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Changes in times of COVID-19 — a longitudinal study on teacher agency and digital transformation

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Drawing from agency theory, this study investigates the critical role of teachers in the digital transformation of education, exploring how technological advancements are redefining educational institutions and instructional methodologies. Employing a longitudinal qualitative methodology from 2020 to 2022, we engaged with 10 secondary education teachers and analyzed 30 interviews to identify transformative shifts and intricate relationships over time. Our analysis highlights how teacher agency, institutional changes, and instructional innovations dynamically interact, with governance mechanisms and infrastructural developments significantly shaping these interactions. We developed a heuristic model that delineates the complex interrelations among individual and collective agency, school leadership, and the broader educational context, aiming to facilitate the adaptation of instructional practices and institutional norms for effective digital transformation. This study provides vital insights for educators, leaders, and policymakers on navigating and influencing the educational landscape during and post-pandemic, emphasizing the importance of strategic leadership and adaptive policy frameworks.

KEYWORDS
21st century abilities, digital transformation, lifelong learning, media in education, teacher agency, teacher professional development

Introduction

One of the currently largest and most significant challenges of educational systems worldwide is digital transformation[1] (European Commission, 2020; Ferrari, 2012). This transformation involves more than just the adoption of technology; it redefines how educational institutions operate, deliver value, and interact with all stakeholders (Davies and West, 2014). Educational policy documents emphasize the need for a pedagogically meaningful integration of technologies to foster digital competencies, identifying it as a

[1]Digital transformation refers to the process of integrating digital technology into various aspects of an organization or society to fundamentally change how it operates, delivers value, and interacts with stakeholders (Organisation for Economic Co-operation and Development [OECD], 2019); this involves the adoption of digital tools, technologies, and practices to enhance efficiency, effectiveness, and innovation in processes, services, and products. For schools, this means that they must be capable of preparing students for a digitally influenced world (Ilomäki and Lakkala, 2018). It also demands a rethinking of pedagogical approaches to ensure that digital competence is not just an add-on but a fundamental aspect of education (Schubatzky et al., 2023; Wohlfart and Wagner, 2023).

comprehensive task that spans all levels of instruction and administration (Baker, 2021; European Commission, 2020; UNESCO, 2021).

Within these transformative processes, teachers as agents of change play a pivotal role – navigating between preserving traditional methods and adopting new, technology-driven approaches (Bridwell-Mitchell, 2015,; Keese et al., 2022; Leander and Osborne, 2008; Sebastian et al., 2016 Wohlfart and Wagner, 2023);. Their role as agents involves deciding whether and how to evolve or maintain established practices, navigating between traditional methods and new, technology-driven approaches. Thus, at the core, teachers, as agents, decide whether and how institutionalized practices evolve or remain unchanged across time (Bridwell-Mitchell, 2015), highlighting the need for teacher agency.

The COVID-19 pandemic accelerated this digital transformation, catalyzing both instructional and institutional changes (Wohlfart et al., 2021). However, the sustainability of the initiatives from this period has been a subject of debate (López-Estrada et al., 2026; West, 2023). The pandemic highlighted the importance of technology in education and the need for its thoughtful integration to support long-term goals, rather than just emergency responses. Therefore, the aim of this study was to gain a deeper understanding of the dynamic relationships between teacher agency and institutional and infrastructural changes in the context of the rapid digital transformation initiated by the COVID-19 pandemic and the subsequent two-year period.

Teacher agency — theoretical background

In addressing the dynamics of digital transformation, our theoretical background synthesizes insights from institutional agency, collective agency, leadership, and infrastructural development. Digital transformation in this context is defined as the integration of digital technologies into all areas of schooling, fundamentally altering how educational services are delivered, how teachers interact with students, and how schools operate at a systemic level. These factors collectively inform the significant instructional and institutional changes highlighted in our study, reflecting a comprehensive view of digital transformation not only as technological integration but also a profound shift in educational practices and structures.

Teacher agency: navigating institutional and instructional change

Teachers, as institutional agents, possess the authority and capacity to shape educational practices, curriculum development, and classroom culture significantly. This agency enables them to contribute to the evolution and sometimes the dismantling of existing institutional structures, impacting the governance and operational norms of their educational settings (DiMaggio, 1988).

When confronted with instructional and institutional change, teachers have a range of responses available, including adapting, ignoring, or adopting transformation (Priestley et al., 2012) or as Buchanan (2015) concludes: 'stepping up' or 'pushing back' (p. 710). Consequently, teacher agency should not be assumed to be inherently positive for reform and development (Imants and Van Der Wal, 2020; Kneen et al., 2023). Previous research has emphasized a range of factors that influence teacher agency and their willingness and ability to experiment with instructional change, such as teaching experience and identity formation, as well as the availability of resources and support structures (Coburn, 2004; Hargreaves, 2005; Hökkä et al., 2012; Lockton and Fargason, 2019). In addition, a supportive and empowering school culture that values teacher voice, autonomy, and collaboration can enhance teacher agency and create an environment that invites innovation and change (Leithwood and Jantzi, 2006; Spillane, 2006). Hence, their agency is not only their capacity to act but also their ability to act within a specific context, linking to changes on both institutional and instructional levels.

Within the scope of digital transformation, teacher agency extends to interaction with new technologies, where teachers assess and integrate digital tools into their pedagogical practices (Ilomäki and Lakkala, 2018). Such integration often necessitates navigating complex bureaucracies and adjusting to new pedagogical realities, where the infrastructure's role becomes crucial (Wohlfart and Wagner, 2023). Digital transformation thus directly influences the scope and nature of teacher agency by providing new tools and platforms that can either empower or challenge existing pedagogical practices (Willis et al., 2023).

Collective agency, as demonstrated through collaborative efforts among teachers, amplifies the potential for transformation (Vennebo and Ottesen, 2015). This form of agency manifests in shared goals and collaborative practices that collectively shape institutional policies and practices as well as instructional change (Hargreaves, 2007). We follow Leander and Osborne (2008) in constructing 'a perspective from teachers outwards, a perspective that traces the multiple and multidirectional linkages of the personal, social, and institutional' (p. 25). In this sense, teachers as agents are not viewed as isolated individuals but as collective entities comprising individuals and mediational means, such as language, technology, or policy mandates (Lasky, 2005).

Previous studies have highlighted that teacher collaboration plays a significant role in how teachers perceive and respond to reform initiatives and transformation processes on an institutional level (Hargreaves, 2007; Lockton and Fargason, 2019). While productive discussions and conflict can facilitate inquiry, learning, and change, collaboration may reinforce existing beliefs and practices if there is a lack of diverse perspectives or if certain beliefs are privileged due to power dynamics (Sutton and Shouse, 2019). Less cohesive social networks may thus actually support innovation and the spread of innovative ideas among teachers (Lockton and Fargason, 2019).

The strength of collective agency lies in its capacity to unify diverse teacher experiences and insights, creating a powerful force for comprehensive transformation. Schools that foster strong collective agency among their staff have been found to have profound and enduring changes, which are often more aligned with the needs and realities of the educational community (Hargreaves, 2007).

Integrating leadership and environmental factors into the framework of agency and transformation

Next to school culture and cooperation, leadership practices have been highlighted as pivotal in cultivating an environment that supports or inhibits change (Sebastian et al., 2016). Leaders shape the culture and strategic direction of schools, influencing how policies and innovations are implemented (Diamond and Spillane, 2016; Fullan, 2010; Sanders, 2014). Effective leadership that values teacher voice, autonomy, and collaboration thereby significantly enhances both individual and collective teacher agency (Grissom et al., 2021; Leithwood and Jantzi, 2006; Spillane, 2006). Essentially, leadership practices can either empower teachers, fostering an environment of innovation and change, or constrain them, reinforcing existing barriers to (digital) transformation (Schmitz et al., 2023).

The agency of teachers is further shaped by environmental factors, such as the structural and cultural features of the school, where administrative directives, policy implementation, infrastructure, resource availability, and internal power dynamics can hinder their agency and efforts to change the status quo (Lockton and Fargason, 2019). Therefore, the development and support of technological infrastructure are pivotal in enabling and sustaining the digital transformation of education. Infrastructure not only supports the practical aspects of technology integration but also influences the strategic direction of educational innovation (Coburn, 2004). Moreover, infrastructure's adequacy directly impacts the scope and effectiveness of teachers' agency: Where infrastructure is robust, teachers are more likely to experiment with and adopt innovative practices (Ilomäki and Lakkala, 2018). Conversely, inadequate infrastructure can stifle innovation and reinforce traditional practices that may not align with contemporary educational demands.

In our perspective *from teachers outwards* (Leander and Osborne, 2008), we want to better understand processes of institutional and instructional changes within digital transformation as a result of the COVID-19 pandemic. While teachers can play a crucial role in driving digital transformation, the resulting shift to distance teaching or online learning placed them in a challenging position (Keese et al., 2022). They had become both agents of and, to some extent, captives of the rapid digital transformation of society and the corresponding expectations for education, as they were compelled to utilize digital technologies (Li and Yu, 2022; Wohlfart et al., 2021).

Teacher agency and organizational context are therefore conceptualized as reciprocally related rather than as independent or unidirectionally connected phenomena. Structural and cultural conditions shape the opportunities and constraints within which teachers can act. At the same time, teachers' individual and collective actions can contribute to changes in instructional practices, collaborative routines, and institutional arrangements. These changes may subsequently become part of the organizational context that enables or constrains further action. Teacher agency is thus situated within existing structures while potentially contributing to their reproduction or transformation over time.

The exceptional conditions of the COVID-19 pandemic require a distinction between externally mandated change and teacher agency. School closures and subsequent regulations substantially constrained teachers' available courses of action and, particularly during the initial transition to distance teaching, required them to adopt digitally mediated forms of instruction. We therefore do not conceptualize compliance with such requirements, or the use of digital technologies necessitated by them, as teacher agency *per se*. Rather, agency becomes analytically visible in how teachers interpret and respond to these conditions within their respective contexts. From this perspective, externally imposed conditions can constrain the range of possible action while simultaneously creating situations in which teachers exercise agency through their situated responses.

Various journals have published early findings on the impact of COVID-19 on teachers' transition to digital teaching (e.g., Fütterer et al., 2023; Greenhow et al., 2021; Keese et al., 2022; Öçal et al., 2021; Pozo et al., 2021; Stevens et al., 2023; West, 2023; Wohlfart et al., 2021). The longitudinal design further enables us to examine agency as these external conditions change over time. In particular, the return to regular face-to-face teaching provides an opportunity to distinguish temporary adaptations to pandemic requirements from practices that teachers subsequently modified, retained, or discontinued. Continued use of pandemic-introduced practices after the immediate requirement had subsided can therefore provide evidence of teachers' active evaluation and selection of practices, rather than merely their compliance with externally imposed change. We aim to better understand the connections between teacher agency and digital transformation throughout this complex and unique time by answering the following research questions (RQ):

RQ1: How did teacher agency contribute to institutional and instructional changes during the digital transformation induced by the COVID-19 pandemic?

RQ2: In what ways has the interaction between teacher agency and the school's structural and cultural environment influenced the adoption and implementation of digital transformation?

Methods

To address our research questions, we conducted a longitudinal interview study in the federal state of Baden-Wuerttemberg, Germany, across three consecutive years (2020, 2021, 2022). In the state examined, the federal government implemented a suspension of all school activities on March 16, 2020, initially planned to last for one month. As a result, teachers were required to create appropriate learning materials and deliver them to students to facilitate distance learning [Ministry of Culture, Youth and Sport of Baden-Wuerttemberg (Ministerium für Kultus, Jugend und Sport), 2020]. However, schools in Baden-Wuerttemberg remained closed for nearly three months in 2020, with a gradual reopening for smaller student groups in mid-June of that year. In 2021, the teachers had to re-adapt to a new situation once more, as many schools had gone over to a rotating system with half of the classes at home in distance teaching and the other half in the classroom.

Finally, in 2022, teachers and students returned to 'normal' face-to-face teaching.

Instruments, interview conduct and data management

We conducted 30 semi-structured interviews, using three sets of interview guidelines crafted to reflect the specific challenges and contexts of each year. These evolving guidelines helped in exploring the nuanced impacts of the pandemic over time (Denzin and Lincoln, 2018). The interview protocol is detailed in Appendix Table A1. A brief demographic questionnaire complemented the interviews to gather background information on participants, such as age, teaching subjects, and experience.

Interviews were conducted annually via videoconferences, lasted between 34 and 71 min each and were audio-recorded and transcribed verbatim according to the transcription standards outlined by Dresing and Pehl (2019). We ensured the confidentiality of participants by removing or altering identifiable information in the transcripts, which totaled 396 pages of text, representing 22 h of interview time.

Participants

Participants were selected using a purposive sampling strategy, based on Patton (2015) work, to include a diverse range of experiences and perspectives within the secondary education system in Baden-Wuerttemberg (with students aged 10–16 years). Eligibility was restricted to teachers working in secondary education in Baden-Wuerttemberg. The sample was predominantly drawn from public "Gymnasien" (school type) in Baden-Württemberg. Nine participants taught at public Gymnasien, while one participant worked at a boarding-school institution comprising several educational branches, including a primary school, a "Realschule", a general Gymnasium, and two "vocational Gymnasien". Participants were initially recruited through word of mouth and subsequently through snowball sampling, with participants and professional contacts referring other potentially eligible teachers. The selection aimed to represent various stages of professional experience, teaching loads, and involvement in digital transformation processes at their institutions (see Table 1).

Data analysis

The data were analyzed using qualitative content analysis following Mayring (2022) and managed using MAXQDA Analytics Pro 2022. The category system combined deductive categories informed by the theoretical framework with inductive categories developed from the interview material. The first author conducted the primary coding of the longitudinal dataset. Analysis proceeded iteratively through multiple rounds of coding, during which categories and their definitions were refined in relation to the interview material. Category definitions and anchor examples were used to guide the consistent application of the category system; exemplary categories, definitions, and anchor examples are provided in Appendix Table A2. Data from the first interview wave had also been independently analyzed by other members of the research team in the context of studies addressing different research questions. These analyses were therefore not treated as formal intercoder reliability checks for the present longitudinal analysis. In accordance with the interpretive qualitative approach of the study, no quantitative measure of intercoder agreement was calculated. All interviews were conducted in German and translated into English by the first author. Translations were meticulously reviewed to ensure accuracy and fidelity to the original meanings expressed by participants (Denzin and Lincoln, 2018).

Findings

The analysis of the interviews identified changes in both the institutional and instructional contexts of the participating teachers across the three interview waves. The findings are presented in two main sections: institutional changes and

TABLE 1 Participants (sorted by gender).

Pseudonym	Age*	Subjects taught	Teaching experience (in years)*	Length of interviews (in minutes)
M01	50	Music, Physical Education (P.E.), Maths	14	2020: 51 2021: 39 2022: 44 Total: 134
M02	45	Biology, Geography, Ethics, Science, & Technology	15	2020: 35 2021: 48 2022: 34 Total: 117
M03	37	Maths & P.E.	2	2020: 40 2021: 35 2022: 41 Total: 116
M05	31	Maths & P.E.	1	2020: 47 2021: 45 2022: 45 Total: 137
M06	38	German, History, Social Studies	6	2020: 54 2021: 42 2022: 37 Total: 133
M07	38	Spanish, History, Social Studies	6	2020: 42 2021: 42 2022: 40 Total: 124
M08	31	Maths & P.E.	1	2020: 71 2021: 57 2022: 48 Total: 176
W02	60	German & Geography	26	2020: 42 2021: 51 2022: 43 Total: 136
W03	41	Biology, Chemistry, Science & Technology	11	2020: 50 2021: 45 2022: 37 Total: 132
W04	28	Biology & Maths	0	2020: 39 2021: 36 2022: 34 Total: 109

instructional changes. Within these sections, we report changes and differences described by participants across the study period, with particular attention to developments reported in 2020, 2021, and 2022. Where relevant, the findings also show differences between participants and between their respective school contexts.

Institutional changes

Within the institutional context, the analysis identified four categories of change: (1) technological infrastructure, (2) digital integration and collaboration in workspaces, (3) digital leadership, and (4) integration of digital media strategies.

Technological infrastructure adaptation

Across the three interview waves, participants described substantial changes in the technological infrastructure of their schools, although the extent and stability of these developments varied across contexts. In 2020, accounts focused particularly on the rapid expansion of digital infrastructure and uncertainty regarding the availability and permissibility of communication tools, learning platforms, and data-storage solutions. M03, for example, described the speed of the technological upgrade as unexpected and attributed this acceleration partly to the pandemic: 'I didn't expect it [the technological upgrade] to happen so quickly, but the pandemic has certainly played a role in facilitating it' (M03_2021).

Initially, the teachers spoke about challenges in navigating the landscape of online communication tools and data storage platforms. They encountered uncertainties about which tools were allowed, such as Zoom, BigBlueButton, or Itslearning, and with concerns about data storage platforms, such as Moodle, MS Teams, Untis, or Itslearning (W03_2021; W04_2022). Several teachers highlighted the frustration caused by sudden changes and insufficient alternatives (M02_2022; M05_2021). The uncertainties surrounding these platforms created inconvenience and the need to adapt to new solutions. One teacher described the situation, saying:

> The crisis has led to progress, but as I said, many initiatives are started and left unfinished. Even now, we have all become familiar with platforms like Microsoft 365 or Office 365, which worked perfectly for us with Teams. But now they are being shut down without having a perfect alternative. (M02_2022)

Data protection and privacy issues added complexity to the situation. There were debates and considerations related to the use of specific platforms, such as Teams, and concerns about where data were being stored (M03_2022). In addition, gray areas surrounding streaming lessons from classrooms and concerns about privacy (of students and teachers alike) were among the challenges teachers faced (M01_2021). Meanwhile, another teacher noted that privacy concerns were overlooked at the beginning of the pandemic, due to the urgency of the situation:

> […] we wondered about potential hurdles. But when the pandemic hit, those hurdles no longer seemed important. Some processes became faster. We didn't ask every colleague if they agreed to digital teaching; we just did it because it was the only way to reach students. (M03_2020)

In response to concerns about data storage and privacy, some schools decided to set up their own servers. This allowed them to become independent of external servers and maintain control over their data. One teacher mentioned integrating an in-house server in 2022:

> We now have our own server in the basement, and we use platforms like Simla, Moodle, and GiPsy. So, we have made ourselves independent of external servers, and it works 100% because we have skilled IT personnel. (M02_2022)

Over the course of the two years, we identified situations in which teachers appreciated the stability and reliability and a 'sense of security and peace of mind' (M02_2021) that came with improved technology infrastructure in schools (M06_2022; M03_2021).

Digital integration and collaboration in workspaces

The transformation of the digital workspace has been closely tied to the evolution of collaborative practices among teachers. Initially, teachers expressed concerns about the challenges of organizing their communication with students through digital channels, such as email or chat (M02_2020). Over time, email remained the primary mode of communication with parents, although there was a slight increase in communication frequency and a lower threshold for reaching out to teachers for less urgent matters due to the ease of digital communication (M08_2022; M07_2022).

In addition, we identified the intention to continue using digital tools, such as digital class registers and Moodle, an online learning platform, to record attendance, assignments, and other relevant information for students to access (M03_2021; M08_2022) and a shift toward paperless offices, relying primarily on digital means for managing and organizing their work (M02_2021; W02_2021). The digitalization of class organization and daily school routines offered benefits, such as better availability of information and easier collaboration among colleagues, improved organization, and streamlined workflows[2]. Teachers reported scanning or photographing analog materials and converting them into digital formats for easy storage and retrieval, allowing greater flexibility in lesson preparation. However, it also brought the potential for an increased workload and the need for continuous synchronization among teachers (M08_2022).

[2]Digitalization refers to the process of converting information from a physical format into a digital one. Within the context of this study, it specifically denotes the transition from traditional paper-based methods to digital systems for managing educational content and communications.

Furthermore, digital media enabled easier communication among teachers through various channels. This was part of digital collaboration dynamics where teachers used email distribution lists for general communication while also highlighting the effectiveness of chat-based meetings for direct communication within teams (M02_2022, M05_2022) and the use of online platform to share teaching materials. The latter was mentioned by most interviewees, particularly in 2022. However, the establishment of subject-specific material repositories accessible to all teachers is still an aspiration that has not yet been met satisfactorily (M02_2022). The teachers referred to different levels of engagement in online teaching discussions, with some actively seeking and exchanging ideas (W02_2020), while others preferred traditional approaches, such as sharing worksheets without much interaction (M03_2020). Likewise, some teachers reported receiving support from previously overlooked external sources, such as the State Media Center, which offered a range of digital resources and tools. This support greatly facilitated their teaching processes and ensured the alignment of instructional materials with the curriculum (M02_2020).

Digital leadership

Participants reported different approaches by school leadership to managing digital teaching and digital transformation. While one teacher mentioned the challenges in communication and an absence of decision-making (M06_2020), another teacher highlighted the autonomy given by the school leadership in adhering to the schedule and ensuring attendance during online classes:

> It was up to each teacher to determine the duration of the online class […]. The school leadership emphasized following the schedule and checking for attendance, even if it wasn't possible to teach an entire double period. (W03_2021)

In some cases, school leadership provided specific guidelines for digital tools and platforms. One teacher described how their school leadership aimed to minimize the use of multiple platforms from the first year on, stating:

> At our school, it was well-organized and centralized […]. Our school leadership emphasized using as few media or platforms as possible. Initially, it was only Untis and email, but later on, with the transition to Teams, the school leadership communicated the changes. (M05_2020)

The role of school leadership as a support system was evident in various instances. One teacher, W03, praised the extraordinary efforts of their school leader during the pandemic in personally visiting families and 'loaned out tablets that were not being utilized in the school' (W03_2022). Additionally, the presence of competent individuals within the school leadership team, with expertise in media technology and information technology (IT), was appreciated by the teachers (M02_2021).

However, there were instances where leadership support and guidance were lacking. One teacher expressed concerns about the overall appreciation 'where the workload is high, and sometimes school leadership does not fully recognize the importance of digitalization' (M05_2022). Similarly, another teacher highlighted the need for professional IT experts in schools, comparing them to larger companies that have dedicated IT staff:

> In a technologically advanced country like ours, with competent IT professionals and sufficient funding, we should have a secure cloud infrastructure that can be accessed professionally. Each larger school should have an IT expert who manages the system professionally, allowing teachers to focus on teaching. (M02_2021)

In addition to school-level leadership, participants referred to guidance from higher administrative levels. Slow responses from the Regional Council and the Ministry of Education were mentioned as challenges, and M07 reported uncertainty associated with unclear guidelines and changing recommendations in 2021 (M07_2021).

Integration of digital media strategies

The availability of a school-level media concept for integrating digital media into teaching differed across participants' schools and changed over the course of the study. Some teachers initially faced challenges in this regard, while for others, it remained a persistent problem. In 2020, two of the ten participants reported that a media concept was already in place at their school. Across the subsequent interview waves, four additional participants reported that a media concept had been developed at their school. For the remaining four participants, the absence of such a concept persisted through 2022. M03, for example, reported in 2022 that a media team existed at the school but that a comprehensive media concept had still not been established (M03_2022). In addressing the challenges of online teaching, the development of a digital netiquette in the second year of the pandemic, including 'guidelines that both students and parents […] must sign' (M06_2021), was mentioned by one teacher.

Instructional changes

In addition to the institutional changes, we identified the four categories of change within the instructional context: (1) shifts in teaching modalities, (2) evolution of teaching materials, (3) alteration in grading practices, and (4) changes in teacher roles.

Shifts in teaching modalities

Participants' accounts reflected the changing instructional arrangements across the three interview waves. The 2020 interviews focused predominantly on experiences of online

instruction during school closures, while the 2021 interviews included experiences of hybrid or blended arrangements. By 2022, participants had returned to regular in-person instruction. Across the interviews, participants described both positive and negative experiences associated with these different instructional formats.

M01 described negative aspects of online instruction in 2020, including the stress associated with waiting for students' responses and the continuous need for corrections, and referred to these difficulties again retrospectively in the 2022 interview (M01_2020; M01_2022). In contrast, another participant expressed the comfort of being at his desk, possibly at home, and not having to manage an entire class on-site. He mentioned the ease of digital supervision and control over disruptions (M06_2021). Considering hybrid learning, the participants highlighted both positive and negative aspects of this instructional form. The students appeared to be more focused and willing to engage in personal interactions with the teacher in this format than in the sole classroom setting (M03_2020). On the other hand, the participants repeatedly highlighted the importance of personal contact and the positive aspects of returning to in-person instruction in 2022, as expressed by the following teacher:

> Teacher-student relationships work best through personal contact. It needs to be explicitly mentioned that we need that. We cannot simply use online instruction; otherwise, the essence is lost. Therefore, in-person instruction remains crucial. (M02_2022)

Evolution of teaching materials

The use and development of digital instructional materials emerged as a recurring theme across the interviews. In 2020, participants reported different approaches to adapting teaching materials for distance instruction. These included distributing copied worksheets during the lockdown (W02_2020), creating an online media library through the state media center (M02_2020), and producing instructional videos (M05_2020). Some teachers experienced challenges in transitioning their materials to digital formats, particularly those who had not previously engaged with such technology. One teacher expressed the difficulties faced by colleagues who lacked digital resources:

> Many colleagues had to start from scratch. They simply didn't have PDF files or digital worksheets. Their materials were handwritten or something like that. It was certainly more challenging for them. (M02_2020)

In the 2021 interviews, participants described further use of digital tools and resources in their teaching. For example, W02 reported exploring the learning management system Moodle (W02_2021), while M02 and M03 described the use of digital learning resources and digital platforms in connection with teaching and communication with students and parents (M02_2021; M03_2021).

In 2022, participants continued to refer to digital resources in the context of regular in-person teaching. M08 described additional workload associated with preparing and managing digital resources alongside conventional classroom materials, while also referring to possibilities for more personalized instruction through the use of digital media (M08_2022). In the 2022 interviews, participants reported that materials digitized during the preceding two years continued to be used in regular in-person teaching (W02_2022).

Alterations in grading practices

Participants reported changes in grading and grade administration across the three interview waves. These concerned restrictions on grading during distance instruction, subsequent adjustments following the return of formal grading, and the increasing use of digital tools for grade administration. During the initial period of distance instruction in 2020, formal grading was restricted. W04 and M06 reported reduced student engagement in connection with the absence of grades (W04_2020; M06_2020). W04 described this experience as follows:

> 'Many students dropped out when they realized that there wouldn't be any grades due to the grading restrictions. It was a moment when students realized that it wasn't just a short-term change but something that would continue for a while.' (W04_2020)

In the 2021 interviews, participants described adjustments associated with the return of formal grading and the transition to hybrid learning. W04 and M06 referred to learning gaps following the period of online instruction and to students' difficulties in readjusting to formal grading after the preceding period without grades (W04_2021; M06_2021).

The management of grades also underwent a digital transformation, with the teachers adopting online platforms for grade administration, including remote access. One teacher described the progression from using physical copies and document cameras to scanning and creating PDFs, allowing for greater flexibility and convenience in grading (M01_2021). Additionally, the utilization of organizational platforms, such as Moodle for file transfer, collaborative discussions, and school management, became integral to grading processes over time—enabling teachers to enter grades remotely and facilitating online communication and organization (M08_2022).

Changes in teacher roles

Across the three interview waves, participants reported changes in their interactions with students and parents, the organization of instruction, and the boundaries between work and personal life. During the initial phase of online instruction, the teachers faced the challenge of engaging with unresponsive students. One teacher described his efforts to reach out to students through emails and phone calls, ensuring that they

submitted assignments and addressing any difficulties they encountered:

> I spent a lot of time trying to connect with students who were not responsive. I had to obtain their email addresses through the class teacher, and for those who still didn't respond, I called them. (M01_2020)

Participants reported different views on the use of streaming during hybrid instruction. M02 described a positive response from parents, who preferred streamed lessons to receiving frequent paper-based assignments (M02_2021). In contrast, W02 and M01 expressed reservations about streaming lessons, including concerns that this form of teaching was not part of their contractual responsibilities (W02_2021; M01_2021). Following the return to in-person teaching, M03 reported increased workload associated with the resumption of additional activities, such as organizing events and concerts alongside regular teaching duties (M03_2022).

In the 2022 interviews, participants described changes in their classroom practices associated with the use of digital devices. The use of digital tools allowed for a less teacher-centered approach, increased openness in instructional methods, and the incorporation of current events through easy access to the internet (W03_2022). However, some teachers acknowledged the potential drawbacks of moving away from traditional textbook-based instruction and occasionally questioned the effectiveness of their digital teaching practices. One teacher remarked:

> When I allow students to use digital devices in class, my teaching becomes less teacher-centered and more open. I also find that my lessons have become more up-to-date by easily integrating current information from the internet. However, I sometimes wonder if relying less on the textbook, as we used to do, is always the best approach. (M07_2022)

The teachers appreciated the enhanced direct contact and feedback from the students and parents facilitated by digital communication tools (M07_2020). On the other hand, the teachers recognized the need to maintain a healthy work–life balance and avoid being constantly available (M02_2021; M07_2022). The teachers reported an increased workload and difficulty disconnecting from work due to constant digital accessibility (M03_2022). The blurring of boundaries between personal and professional life was a common concern: 'The line between work and personal life is increasingly blurred, or sometimes there's no line at all between "I'm working" and "I'm not working" or "I'm sick"' (M05_2022). In terms of personal connections and understanding the students' well-being, the teachers expressed concerns about the limitations of online teaching. The lack of face-to-face interaction hindered their ability to observe the students' emotions and address their individual needs effectively. One teacher shared:

> Overall, the pandemic period has changed things in a way that we were no longer as accessible as a contact person for students. We didn't have that daily contact anymore, where we could notice if something was wrong. […]. However, the use of technology, […], allowed students to feel a bit closer to us and provided them with the opportunity to ask questions or express their concerns. But, I still believe that the time we spent on things beyond teaching during this period was severely reduced due to the lack of direct contact with students. (W04_2020)

Digital communication remained part of participants' accounts after the return to in-person teaching. W03 reported in 2022 that digital communication enabled students to contact teachers quickly with questions (W03_2022). At the same time, M03 reported that students' engagement with digital communication platforms had declined following the return to in-person instruction (M03_2022).

Discussion: synthesizing change and agency

Our analysis of institutional and instructional changes across the three interview waves provides the empirical basis for addressing RQ1 and examining the relationship between digital transformation and teacher agency (RQ2; see Figure 1). At the institutional level, the identified developments concerned technological infrastructure, digital collaboration and work organization, leadership practices, and school-level digital media strategies. At the instructional level, changes related to teaching modalities, instructional materials, grading practices, and teachers' professional roles. Considered together, these themes illustrate that pandemic-related digital transformation extended beyond the introduction of new technologies and involved changes in both the organizational conditions of teaching and teachers' instructional practices.

In addressing RQ2, our discussion links the observed changes to the concept of teacher agency. The findings demonstrate that teacher agency not only influences but is also influenced by the broader institutional responses to digital demands. This reciprocal relationship highlights the complex interplay between individual actions and systemic changes, which is critical for understanding the mechanisms of digital transformation in educational settings (Lockton and Fargason, 2019). Based on these findings, we discuss how *teacher agency* and *collective agency* are associated with the digital transformation process during the pandemic and what role *leadership* and *(governmental) constraining rules and regulations* play in this process. We then reflect on the special role of infrastructural development as identified in our study and conclude with an illustration of the complex interplay of stakeholders and processes for digital transformation.

Individual and collective agency

The findings require a distinction between externally imposed change and teacher agency in responding to that change. Particularly during the initial phase of the pandemic, the transition to distance teaching was not primarily initiated by

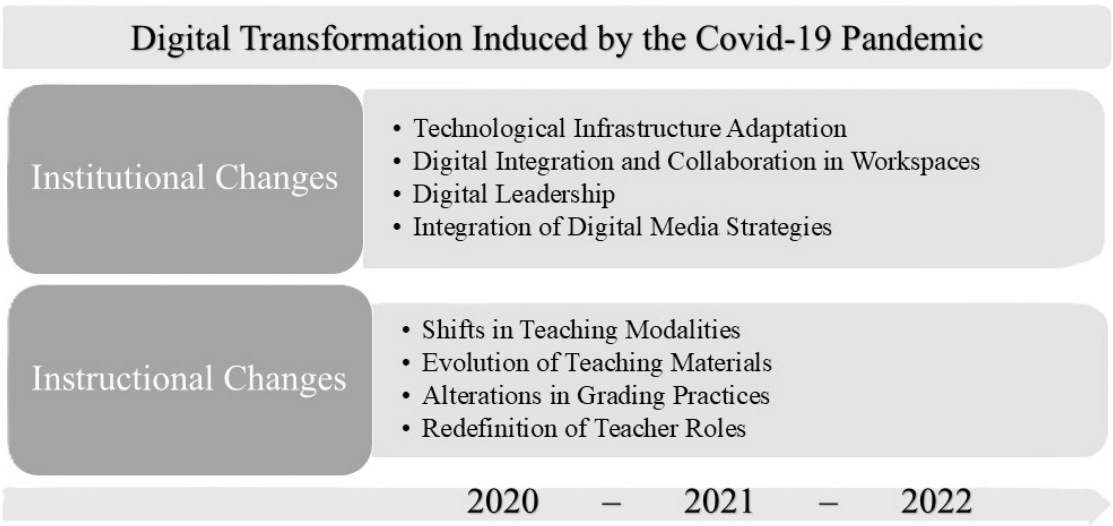


FIGURE 1
Institutional and instructional changes for digital transformation induced by the COVID-19 pandemic.

teachers but resulted from school closures and regulatory requirements. Such required adaptation should therefore not in itself be interpreted as evidence of teacher agency. Rather, agency became visible in how teachers responded within these externally defined conditions, for example, by selecting and adapting digital tools and teaching materials, organizing communication, or negotiating emerging expectations. In this sense, teachers' abilities to respond to new educational demands can be understood in relation to their professional autonomy and the situated nature of agency (Buchanan, 2015), rather than equating the compulsory adoption of digital technologies with agency *per se*.

This distinction is particularly relevant from a longitudinal perspective. While emergency regulations initially defined restrictive conditions for teachers' actions, subsequent changes in instructional arrangements also altered the circumstances under which professional decisions were made. Agency was therefore not absent during the initial pandemic phase and merely re-established afterwards; rather, its expression needs to be understood in relation to changing structural conditions. Individual agency remained constrained by contextual factors (Cohen and Mehta, 2017), including limited time for professional development and the additional demands associated with adapting instructional practices. Moreover, the rapid transition of educational systems to online teaching involved limited consultation with teachers (West, 2023, p. 450), further illustrating the tension between externally initiated transformation and teachers' opportunities to shape its implementation.

Alongside individual agency, collective agency provides an important perspective on the relationship between teachers' actions and their organizational environment. Collaborative networks, leadership, and established school and departmental cultures can support individual and collective action by facilitating the exchange of knowledge, resources, and professional experience (Diamond and Spillane, 2016; Hargreaves, 2007; Lockton and Fargason, 2019). In this respect, the collaborative practices identified in our study resonate with Bridwell-Mitchell (2015) emphasis on the relationship between social interaction and innovation in addressing instructional challenges. Such collaboration is relevant not only to the initial development of instructional practices but also to their subsequent adaptation within changing institutional conditions.

From this perspective, the selective continuation of pandemic-introduced practices can be understood as part of the ongoing relationship between individual and collective agency and the organizational context. The persistence of digital practices is not necessarily determined by their initial adoption under exceptional circumstances; rather, it also depends on how teachers evaluate their continued relevance and how collaborative and institutional conditions support their use. Collective agency may therefore contribute to longer-term instructional and organizational development (Vennebo and Ottesen, 2015; Virkkunen, 2006), without implying that all pandemic-related innovations are necessarily sustained or result in comprehensive institutional transformation. This interpretation highlights digital transformation as an evolving process in which teachers' individual and collective actions interact with changing structural conditions.

Leadership and constraining rules and regulations

Our findings reveal that school leaders significantly influenced digital integration,

Our findings illustrate the relevance of school leadership for shaping the institutional conditions of digital transformation. Leadership practices could both facilitate and constrain the integration of digital technologies, reflecting the relationship between organizational arrangements and collective agency (Sebastian et al., 2016). Decisions concerning digital platforms, communication structures, and the coordination of instructional practices influenced the conditions within which teachers

exercised their professional agency. In this respect, leadership was relevant not only to the implementation of technological changes but also to the ongoing development of institutional routines and expectations (Diamond and Spillane, 2016; Grissom et al., 2021; Leithwood and Jantzi, 2006).

At the same time, school leadership operated within a regulatory environment that was itself subject to considerable change and uncertainty. The interpretation and implementation of educational policies therefore constituted an important dimension of institutional transformation (Spillane, 1999). Particularly during the initial pandemic phase, uncertainty surrounding permissible digital platforms and data protection requirements complicated the coordination of digital teaching. Such regulatory conditions did not simply prescribe technological choices; they also shaped the scope for institutional decision-making and, consequently, the opportunities available to teachers to develop and adapt their instructional practices.

The findings further suggest that schools responded to these conditions in different ways, including through decisions concerning platform use and locally managed technological solutions. These developments illustrate how institutional actors interpreted and responded to regulatory requirements within their respective organizational contexts. However, such responses should not be equated with unrestricted institutional autonomy, as schools continued to operate within externally defined legal and policy frameworks. The relationship between leadership, regulation, and teacher agency must therefore be understood as context-dependent rather than as a straightforward distinction between enabling leadership and constraining policy.

From a longitudinal perspective, these institutional conditions remained relevant beyond the initial transition to emergency distance teaching. As instructional arrangements changed, leadership decisions and organizational expectations continued to shape the circumstances under which digital practices could be maintained, modified, or discontinued. The challenges associated with evolving regulatory requirements thus underline the importance of coordination between educational authorities, school leadership, and teachers in processes of digital transformation (West, 2023). Rather than treating institutional change as a purely top-down process, the findings point to the need to consider how regulatory frameworks and leadership practices interact with teachers' situated professional actions.

Infrastructural development for digital transformation

Our longitudinal findings highlight the importance of perceiving infrastructure development as an ongoing, indispensable, and evolving process. At an individual level, infrastructural development provided the necessary technological foundation for teachers, colleagues, and leaders to exercise agency, collaborate, implement changes, and navigate the evolving educational landscape, creating a supportive environment for teachers to exercise their agency effectively (Lockton and Fargason, 2019).

Over time, improvements in digital infrastructure created additional opportunities for teachers to share teaching materials, resources, and ideas. Collaborative platforms, communication tools, and file-sharing systems supported exchange among colleagues, although their availability and integration varied across institutional contexts. Additionally, infrastructural development over the two years supported leadership in providing guidance and support to teachers by leveraging technology infrastructure to disseminate guidelines, communicate expectations, and offer professional development opportunities related to instructional changes.

The development of adequate infrastructure, encompassing hardware, software, and network components, provides an important foundation for the integration of digital tools, platforms, and systems at the institutional level. Our findings illustrate how these developments supported processes such as data management, collaboration, and communication, while also creating opportunities for changes in instructional formats, teaching materials, grading practices, and teachers' professional roles. However, the availability of digital infrastructure alone does not necessarily ensure the continued use of pandemic-introduced practices. The longitudinal findings suggest that their persistence also needs to be considered in relation to their perceived instructional or organizational usefulness and the demands associated with their continued use. Accordingly, some digital practices remained part of teachers' work after the return to face-to-face instruction, whereas others became less prominent. This differentiation emphasizes the interdependence of technological conditions, organizational contexts, and teachers' situated decisions in processes of digital transformation.

Teacher agency and insistutional change: resciprocal dynamics

In summary, our findings point to a reciprocal relationship between teacher agency and institutional and instructional change in digital transformation. Leadership decisions, technological infrastructure, and regulatory requirements shaped the opportunities and constraints within which teachers developed and adapted their instructional practices. At the same time, teachers' individual and collaborative responses contributed to changes in everyday school routines, including digital communication, material sharing, and the organization of teaching. These developments did not necessarily result in comprehensive or uniformly established institutional structures, as illustrated by the differing availability of school-level media concepts and shared material repositories. Digital transformation can therefore be understood neither as an exclusively top-down process nor as the direct outcome of individual teacher initiatives, but as an evolving interaction between institutional conditions and teachers' situated practices.

Figure 2 serves as a heuristic model designed to synthesize the interconnected elements identified in our study and to illustrate the reciprocal dynamics of digital transformation. It depicts how teacher agency, collective agency, institutional change, and instructional change are interrelated within broader technological and regulatory conditions. Rather than suggesting fixed causal relationships, the model emphasizes how institutional arrangements shape teachers' opportunities for action, while teachers' individual and collaborative practices

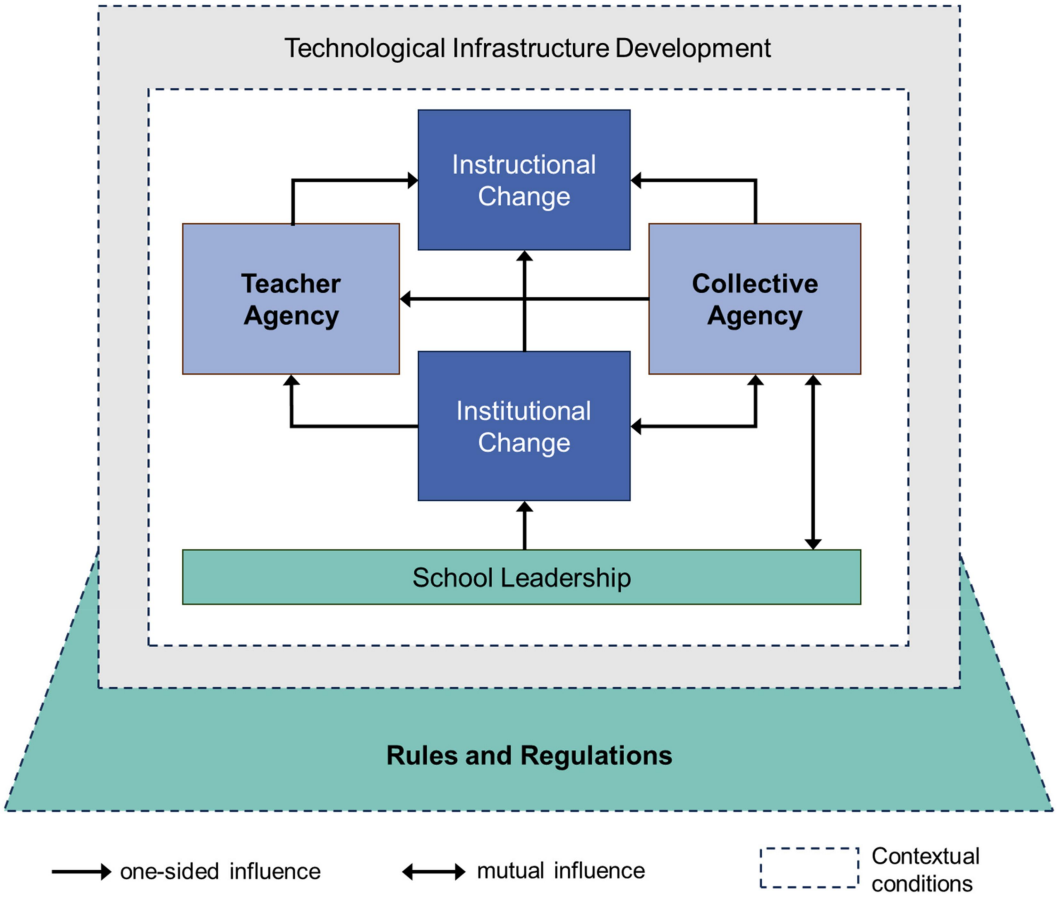


FIGURE 2
Interconnected dynamics of teacher agency, collective agency, and institutional and instructional change in digital transformation. Solid arrows indicate relationships between the depicted elements, while dashed outlines represent overarching contextual conditions within which these processes unfold.

may, in turn, contribute to the adaptation of instructional and organizational routines.

The figure challenges readers to consider how these dynamics might play out in different educational settings, encouraging a deeper exploration of how digital transformation can be managed effectively within their own contexts. It raises questions about the roles of leadership in facilitating or hindering digital adoption and how policies might be crafted to support teacher agency more effectively.

Discussions around Figure 2 also highlight the need for educational leaders and policymakers to engage with teachers actively as they navigate digital transformation. This engagement is crucial for ensuring that changes in educational practices are not only technologically feasible but also pedagogically sound and aligned with the teachers' professional development needs based on their lived experiences in considering how to continue, what to abandon and what needs to be invented fresh (West, 2023).

International relevance of findings and limitations

In an era where policy frameworks often lag behind technological advancements, our study highlights the intricate relationship between regulations and teacher agency in a global context. While the challenges highlighted in our study have been discussed in various countries with some variation but also strong similarities (Greenhow et al., 2021; Keese et al., 2022), our findings offer a German perspective on the challenges faced by teachers in this specific context. Furthermore, our findings prompt a critical reevaluation of the situation post-pandemic. We agree that digital transformation alone is not the panacea for enhancing education in a student-centered environment. Instead, it requires teachers with agency making informed decisions, coupled with a willingness to engage in critical reflection.

When assessing the limitations of our study, it is crucial to recognize that our exploration of the educational landscape in the digital age was based solely on qualitative data from one country. First, we acknowledge the limitation of the relatively small sample size. The selection of a small number of participants was partly driven by the nature of our research approach. To establish rapport and build trust with the participants, we conducted multiple interviews with each individual over an extended period of time. This longitudinal approach allowed us to develop a meaningful relationship with the participants, fostering an atmosphere of openness and honesty. By engaging in ongoing dialogue and revisiting topics, we aimed to encourage the participants to share their genuine

experiences and feelings, even if they deviated from societal norms or expectations.

Second, our figure, which we refer to as a data-based heuristic model, underscores the dynamic and exploratory nature of our study. A heuristic serves as a tool for exploration, encouraging us to ask questions, provoke thought, and discover new avenues of understanding rather than prescribing a fixed set of relationships or predicting outcomes. In line with recent methodologies, such as the systematic process of thematic analysis to develop a conceptual model in qualitative research described by Naeem et al. (2023), our approach to developing this heuristic model involved both inductive and deductive coding to ensure a rigorous and replicable content analysis.

Conclusion and outlook

The longitudinal interviews provided insights into how teacher agency drove institutional and instructional changes in Germany during the COVID-19 pandemic. The findings highlight the importance of both individual and collective transformative agency in initiating and sustaining instructional changes. However, the success of the transformation process depends on the presence of supportive structural and contextual conditions.

As for future research, our study opens up several important pathways for further investigation. Longitudinal qualitative research, as employed in this study, can continue to provide valuable insights into the evolving landscape of education in the digital age. Future research could expand on this foundation by incorporating quantitative elements to explore statistical trends and relationships. Additionally, exploring the experiences of other stakeholders, such as students and parents, can offer a more comprehensive perspective on digital transformation in education. Furthermore, investigating the impact of varying infrastructural development approaches on teacher agency and institutional and instructional changes can provide critical insights for educators, policymakers, and researchers in the ongoing quest to enhance education in the digital era. Finally, we emphasize a critical reminder: the longitudinal nature of our study encourages a reflective assessment of the post-pandemic situation. While teacher agency has been instrumental in driving transformative changes, it is essential to recognize that digital transformation alone is not a panacea for advancing education in a student-centered environment. Beyond technological aspects, the success of future educational initiatives will depend on individuals with agency making informed decisions and being open to ongoing critical reflection. As we navigate the evolving educational landscape, it is imperative to consider the lasting impact of the pandemic and adopt thoughtful, adaptable approaches to education.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Karlsruhe Institute of Technology. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

OW: Writing – review & editing, Formal analysis, Writing – original draft, Methodology, Data curation, Visualization, Investigation, Conceptualization. IW: Resources, Conceptualization, Funding acquisition, Validation, Visualization, Supervision, Methodology, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

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Appendix

TABLE A1 Semi-structured interview guide overview for 2020, 2021, and 2022.

Year	Focus	Questions
2020	Adapting to distance teaching; technology implementation and acceptance; transformation of role as teacher	How are you experiencing the situation without face-to-face teaching? How was the transition to digital teaching organized in your school? How was the transition to digital teaching for you personally? How do you currently perceive the use of digital media in your teaching? How has the use of digital media during the COVID-19 period changed your role as a teacher? How does the absence of face-to-face teaching affect your personal life? What role do digital media play in your personal life? How will the integration of digital media be in the upcoming face-to-face teaching? If you had unlimited resources, what would your ideal digital solution for your school look like in order to enhance the effectiveness of your job?
2021	Implementation of digital media in teaching; classroom disruption; digital transformation process	How have you been as a teacher since our last conversation? Which digital media are you currently using in your teaching? How do you currently perceive the use of digital media in the classroom? What new digital experiences/tools (from online teaching) will you continue to implement after the pandemic? Based on the results of last year's interviews, we found that certain factors have a significant influence on the use of digital media: - For example, regulations and guidelines from school management played a crucial role in your own use of digital media. How do you assess this in your case? - The available technical infrastructure also played a significant role. Have there been any changes for you in the past year? - Finally, some teachers mentioned the significant heterogeneity of students as a barrier to the free use of digital media. What does that look like today?
2022	Technology acceptance and digital transformation	What does your current professional daily routine as a teacher look like? Which digital media do you currently use in your teaching? And how? How do you currently perceive the use of digital media in the classroom? What would currently help you to use digital media better/more/following a more meaningful approach? Which factors currently have the strongest influence on your use of digital media? [Questions regarding identified external factors: (1) regulations and guidelines, (2) technical infrastructure, (3) heterogeneity of students and teachers/colleagues] What changes/developments regarding digitalization come to mind? What role did school management play in this transformation process over the past two years?

TABLE 2 Exemplary overview of the main category 'instructional changes' and accompanying subcategories of the interviews as well as associated definitions and anchor examples.

Main category	Definition main category	Subcategory	Definition subcategory	Anchor example
Instructional Changes	Statements expressing different facets of changes in instructional practice with reference to digital transformation.	Modification of instructional formats	Statements expressing modifications of instructional formats with reference to digital transformation.	'And what is increasingly […] developing, are interactive tools for mathematics or interactive pages, where the students have the advantage of receiving direct feedback. Meaning, they work on something or calculate something and provide the solution or formulate the solution, press 'Evaluate,' and there is direct feedback. And, of course, this is a clear added value compared to working with the book, that's obvious.' (2022_M05)
		Evolution of teaching materials	Statements expressing the evolution of teaching materials with reference to digital transformation.	'In history, I recently worked with a relatively new app. With a VR app, Virtual Reality, where the goal was to project reports from Holocaust survivors into the classroom, so to project the person into the classroom with the iPad, and then they would tell something and make this report seem authentic.' (2022_M07)
		Alteration of grading practices	Statements expressing alteration of grading practices with reference to digital transformation.	'It is certainly indispensable in its form that you can access almost everything from home, that you can enter grades from home for most grade levels, and yes, also room reservations or such, that it all works online.' (2022_M08)
		Transformation of teachers' role	Statements expressing transformation of the teachers' role in the classroom with reference to digital transformation.	'Students also find it easier to write to teachers via Teams, just in the chat. There's no longer such a big hurdle as if they had to use the official email. And, of course, you can also share homework, media, in Teams. So, that's definitely an advantage.' (2022_W03)