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Research paper

Digital learning in schools: Which skills do teachers need, and who should bring their own devices?

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ABSTRACT

We investigated factors that are potentially associated with teaching and learning with digital technology, by replicating and extending Sailer, Murböck, and Fischer's (2021) study with a representative sample of 407 German secondary school teachers. In line with the replicated study, teachers' technology-related teaching skills were crucial for different forms of students' active learning, whereas the digital technology equipment available in a school was less important. School support was positively related to successful digital teaching and learning at schools. The success of Bring-Your-Own-Device depended on who brought the device, teachers or students.

1. Introduction

Teaching and learning with digital technology in educational institutions (e.g., schools) is a longstanding recommendation in international and national frameworks and in policies on adapting to the demands and possibilities of rapid digitalisation (OECD, 2015; Redecker & Punie, 2017). Generally, teaching with digital technology can have a positive impact on students' learning outcomes (Tamim et al., 2011). To achieve this positive outcome, teachers may best utilise digital technology by actively incorporating it into their complex teaching processes in such a way that it fits their learning objectives and teaching context (Dillenbourg, 2013; Scheiter, 2021). This way, they can promote students' learning in specific subject areas along with students' digital technology skills (Fraillon, Ainley, & Schulz, 2020). However, studies often focus solely on the frequency of teaching with digital technology, but teaching with digital technology more often does not automatically lead to more effective teaching in terms of better learning outcomes for students (Tamim et al., 2011). Therefore, several studies have pointed to a more student-centred focus, specifically on students' cognitive activation through learning activities (Antonietti et al., 2023; Fütterer, Scheiter, Cheng, & Stürmer, 2022). In the present study, we investigated teachers' initiation of learning activities with digital technology (digital learning activities) to provide an approximation of students' cognitive activation (Chi & Wylie, 2014), in addition to measuring the frequency of teaching with digital technology.

To better understand how teachers integrate digital technology into their classrooms, a complex set of factors that might influence this integration needs to be investigated (Scherer, Siddiq, & Tondeur, 2019). Studies have indicated both teacher-related and school-related factors that are positively related to teaching with digital technology (Drossel, Eickelmann, & Gerick, 2017; Sundqvist, Korhonen, & Eklund, 2021). However, these factors and measurements have been inconsistent across studies, which has partially led to inconclusive results on how these factors are related to digital teaching and learning. Consequently, there is, first, a need to replicate these studies to determine whether their results are reliable and reproducible — a need that has generally received growing recognition in education and psychology (Plucker & Makel, 2021). Second, there is a need for a comprehensive and coherent model for the school context that describes the interplay of different factors related to digital teaching and learning.

An established model defining such factors in higher education is the C♭-model (**C**ontextual **f**acilitators for **l**earning **a**ctivities involving **t**echnology in higher education; pronunciation: cee flæt; Sailer, Schultz-Pernice, & Fischer, 2021). A key feature of the model is its focus on students' learning outcomes as a central benchmark of effective digital teaching and learning. Additionally, it puts students' digital learning activities central as those are the most proximal factors to cognitive learning processes (Chi & Wylie, 2014). Further, it considers

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various teacher-related factors and school-related factors identified in empirical research, which are assumed to have an indirect effect on students' learning outcomes through student learning activities (Sailer, Schultz-Pernice, & Fischer, 2021). The C♭-model (C♭) has been developed for the higher education context and has already been partially validated (Lohr et al., 2021). However, it is inspired by and partly based on research from the school context, and we propose that it can possibly be used in the school context as well.

Against this background, we have two objectives with the current study: First, we aim to replicate a study by Sailer, Murböck, and Fischer (2021), who surveyed 410 teachers in German secondary schools in 2017. The authors investigated the relationships of three factors (i.e., basic digital skills, technology-related teaching skills, and the digital technology equipment provided by the school) with the frequency of teaching with digital technology and teacher-initiated digital learning activities. In the following sections, we present their study results as part of the state of research. Second, we aim to expand on Sailer, Murböck and Fischer's (2021) study by including further factors from C♭, namely internet speed and school support. Thus, beyond replicating and extending the study by Sailer, Murböck, and Fischer (2021), we aim to take a step towards developing a comprehensive model of digital teaching and learning in schools, building on C♭.

1.1. Digital teaching and learning in the classroom

The state of research on the frequency of teaching with digital technology suggests that digital technology use is gradually increasing in classrooms (Fraillon et al., 2020; Lorenz et al., 2017). However, the frequency of digital technology use per se is a necessary, but not sufficient condition for effective teaching with digital technology. Instead, an important concept for effective teaching with digital technology, with respect to students' learning outcomes, is students' active learning and cognitive activation (Ertmer & Ottenbreit-Leftwich, 2010; Redecker & Punie, 2017). Students' cognitive activation means that students are mentally engaged with and process learning content, and link novel information with prior knowledge. In the study by Sailer, Murböck, and Fischer (2021), the ICAP (*Interactive Constructive Active Passive*) framework (Chi & Wylie, 2014) was used to differentiate and systematise the concept of students' cognitive activation. The ICAP framework distinguishes between passive (digital) learning activities, and active learning in the form of active, constructive, and interactive (digital) learning activities. Students engaging in passive digital learning activities absorb information from the learning material without being visibly active themselves (e.g. watching a teacher's instructional video). In active digital learning activities, students visibly manipulate the learning material but do not go beyond the given learning content (e.g., answering multiple-choice questions via clicker-based technologies). In constructive digital learning activities, students individually create new ideas and solve problems (e.g., visualizing mathematical functions via a maths software program). Finally, interactive digital learning activities are constructive digital learning activities that additionally include reciprocal interaction between at least two students (e.g., students giving peer feedback in a collaborative digital environment; Chi, 2009; Chi et al., 2018; Chi & Wylie, 2014).

The ICAP framework (ICAP) assumes that students have different kinds of cognitive processes depending on the learning activity. These cognitive processes reflect the state of students' cognitive activation and become – partially – observable through students' actions and products. Cognitive processes are assumed to become more sophisticated when moving from passive to active to constructive to interactive (digital) learning activities, with shallow learning processes in passive and active (digital) learning activities and deep learning processes in constructive and interactive (digital) learning activities (Chi et al., 2018). Furthermore, it is assumed that these cognitive processes are related to students' learning, with the likelihood of advancement of students' complex skills (e.g., problem-solving) increasing from passive to active to constructive to interactive digital learning activities (Chi & Wylie, 2014). ICAP suggests that teachers need to be able to apply the most effective combination of the different types of digital learning activities in a way that fits their teaching goals and the specific context.

Several studies have successfully applied ICAP in the context of digital teaching and learning in schools. These studies have found that teachers initiate passive digital learning activities most often (Antonietti et al., 2023; Fütterer, Hoch, Lachner, Scheiter, & Stürmer, 2023; Sailer, Murböck, & Fischer, 2021; Wekerle & Kollar, 2022). Considering the high potential of digital technology to enable more sophisticated learning activities, teachers are not yet making the most of it (Sailer, Maier, Berger, Kastorff, & Stegmann, 2024; Tamim et al., 2011).

1.2. Teachers' technology-related skills

Teachers' technology-related skills might influence the frequency and approach to teaching with digital technology (Seufert, Guggemos, & Sailer, 2020). In C♭, these skills are one of the important teacher-related facilitators for digital teaching and learning. For teachers' technology-related skills, Sailer, Murböck, and Fischer (2021) distinguished between basic digital skills and technology-related teaching skills (Digital Campus of Bavaria research group [DCB], 2017).

Basic digital skills are considered important for all citizens to ensure their successful participation in an increasingly digitalised world (Carretero, Vuorikari, & Punie, 2017; Fraillon et al., 2020). For teachers specifically, instrumental basic digital skills can function as a foundation for successful teaching with digital technology. Generally, basic digital skills entail a set of knowledge and skills for using digital technology for both personal and professional purposes, such as searching for information, collaborating, or learning via digital technology (KMK, 2017; Siddiq, Hatlevik, Olsen, Throndsen, & Scherer, 2016). Teachers' basic digital skills are considered a necessary foundation but are not sufficient for teachers to effectively orchestrate teaching with digital technology. Teachers additionally need technology-related teaching skills to initiate student-centred active learning in the classroom (DCB, 2017; Ertmer & Ottenbreit-Leftwich, 2010). This idea is in line with the TPACK framework, which argues that teachers need technological-pedagogical knowledge for their teaching (Mishra & Koehler, 2006). Recent advancements in this line of research have focused on concrete skills for teaching with technology (Petko, 2020). Such technology-related teaching skills can be assigned to four different teaching phases: planning, implementing, evaluating, and sharing (i.e., collaborative development of lessons; DCB, 2017; Sailer, Stadler, et al., 2021).

A wide range of empirical studies found that basic digital skills (Hatlevik, 2017; Sundqvist et al., 2021) and technology-related teaching skills (Drossel et al., 2017; Jung, Cho, & Shin, 2019) were positively related to the frequency of teaching with digital technology. In the study we are replicating, Sailer, Murböck, and Fischer (2021) found that basic digital skills were positively related to the frequency of teaching with digital technology ($\beta = .41$), with a medium effect size; but technology-related teaching skills were not.

Regarding cognitive activation, teachers' basic digital skills have been found to be positively related to teachers' ability to cognitively activate their students in more sophisticated learning activities with digital technology (Quast, Rubach & Lazarides, 2021; Quast, Rubach & Lazarides, 2021). Several studies used ICAP to differentiate between different types of digital learning activities. In the higher education context, both basic digital skills and technology-related teaching skills were positively related to higher education teachers orchestrating digital learning activities with a higher proficiency (Lohr et al., 2021). In the school context, the skill component of technology-related teaching skills across the four teaching phases was most strongly positively related to interactive, then constructive, then active digital learning activities across all four teaching phases, and showed no relationship with passive digital learning activities (Sailer, Stadler, et al., 2021). Two further studies showed that teachers' basic digital skills were positively related to teachers' initiation of passive, constructive and interactive digital learning activities, and teachers' technology-related teaching skills were positively related to constructive and interactive digital learning activities (Vejvoda et al., 2023, 2024).

Results from Sailer, Murböck, and Fischer (2021) suggested that teachers' basic digital skills might form a foundation for teachers to initiate digital learning activities, as basic digital skills were positively related to passive ($\beta = .37$), active ($\beta = .29$), and interactive ($\beta = .39$) digital learning activities, with small to medium effect sizes. However, for teachers to initiate the full spectrum of digital learning activities, technology-related teaching skills were important, as they were positively related to constructive digital learning activities ($\beta = .30$), with a medium effect size.

Therefore, although the specific relationships between teachers' technology-related skills and digital learning activities based on the ICAP model are generally mixed, there is evidence of a positive relationship of teachers' technology related skills with the entire spectrum of digital learning activities across studies.

1.3. School support for digital technology integration

Another factor related to the frequency of teaching with digital technology and teachers' initiation of digital learning activities might be the extent to which a school supports digital technology integration (Brečko, Kampylis, & Punie, 2014; Sailer, Schultz-Pernice, & Fischer, 2021). Although the definition of school support differs across studies, facets that have been included consistently are technical support, pedagogical support, and the support of the principal (Quast et al., 2021; Sundqvist et al., 2021). These three are also named in C♭ as facets of (institutional) support.

A lack of adequate technical support (e.g., maintaining digital technology equipment and infrastructure) and pedagogical support (e.g., supporting teachers in effectively teaching with digital technology) are barriers to teaching and learning with digital technology (European Commission, 2019; Fraillon et al., 2020). The principal can play a leading role in school support by setting and communicating a coherent vision and goals for digital teaching and learning, fostering and monitoring the professional development of teachers, creating a supportive environment for digital teaching, and exhibiting a positive leadership style (Dexter, 2018; Ruloff & Petko, 2021).

Results from studies examining the relationship between school support and the frequency of teaching with digital technology have been inconsistent. Some studies reported no relationship (Gellerstedt, Babaheidari, & Svensson, 2018) or even a negative relationship (Drossel et al., 2017). Others found positive relationships regarding certain facets of school support. For example, Gerick, Eickelmann, and Bos (2017) found that pedagogical support was positively related to teachers' integration of digital technology in class but technical support was not. Some studies found a positive, direct relationship between school support and the frequency of teaching with digital technology (Atman Uslu & Usluel, 2019; Hsu & Kuan, 2013), while others found an indirect relationship that was mediated by teachers' beliefs and technology-related skills (Inan & Lowther, 2010; Sundqvist et al., 2021). However, the relationship between school support and teachers' initiation of digital learning activities has rarely been studied. Quast et al. (2021) found that teachers' self-efficacy mediated the small, indirect relationship between school support and teachers' cognitive activation of students in more sophisticated learning activities with digital technology. Hence, the relationship between school support and digital teaching and learning is still largely unclear, and more research is needed. By contrast, in a higher education context, more consistent results suggest that institutional support is positively related to teachers' frequency of teaching with digital technology and to teachers showing a higher proficiency in orchestrating digital learning activities (Lohr et al., 2021; Sailer, Schultz-Pernice, & Fischer, 2021).

1.4. Digital technology equipment and internet speed

For digital teaching and learning to occur in schools, digital technology equipment must be available to all teachers and students (European Commission, 2019). Thus, as described in C♭, it is a prerequisite for digital teaching and learning. One way of providing digital technology equipment in schools is the 1:1 approach, where the school provides each student with their own digital technology device in the classroom (Islam & Grönlund, 2016; Sauers & McLeod, 2018). Whereas stationary digital technology devices are more commonly found in a central place in the school (e.g., computer lab), mobile digital technology devices are portable and can therefore be provided more easily in every classroom and for every student (OECD, 2020). The 1:1 approach and mobile digital technology devices allow for more flexible, student-centred learning and collaborative learning, and they can also have positive relationships with students' learning outcomes and motivation (Fabian, Topping, & Barron, 2018; Harper & Milman, 2016; Islam & Grönlund, 2016).

Another way of promoting a 1:1 ratio of digital technology devices that ties in with the benefits of mobile digital technology devices is Bring Your Own Device (BYOD; McLean, 2016; Rudyanto, Marsigit, Wangid, & Gembong, 2019), where both students and teachers bring their own personal digital technology devices to school. C♭ proposes both BYOD of teachers and students as factors influencing digital teaching and learning. Similar to the benefits of the 1:1 approach and mobile digital technology devices, studies have shown that BYOD fosters more flexible and student-centred learning, as well as positive learning outcomes, attitudes, and motivation, for students and teachers alike (Adhikari, Scogings, Mathrani, & Sofat, 2017; Rudyanto et al., 2019; Schmitz et al., 2024; Song, 2014).

There are also challenges associated with implementing BYOD in schools. First, equity and access to personal devices for all students might not be given, as particularly disadvantaged students may lack access to a digital technology device equipped with the necessary applications (Adhikari et al., 2017; McLean, 2016). Second, compatibility issues related to different operating systems, software and applications, as well as network compatibility with the school internet can occur (Adhikari et al., 2017; Santos, 2020). Third, students might use their personal devices for non-educational purposes in class, and thus become distracted and disengaged from the intended learning activities (Adhikari et al., 2017; Santos, 2020).

A further necessary prerequisite for digital teaching and learning, as described in C♭, is a school's internet speed, as part of the institutional infrastructure. Internet speed is crucial not only for teachers' mere frequency of teaching with digital technology, but also for effectively implementing digital technology (Brečko et al., 2014) and to "fully exploit the benefits of digital learning (…) "(European Commission, 2019, p. 21).

Some studies have explored the relationships of digital technology equipment and internet speed with digital teaching and learning. Sufficient digital technology equipment (including internet speed and available digital technology devices) was positively related to the frequency of teaching with digital technology (Drossel et al., 2017). Implementing a 1:1 approach for digital technology equipment led to teachers integrating digital technology more often in their teaching (Sauers & McLeod, 2018). The introduction of a BYOD approach in a school led to a shift away from teacher-centred, passive learning to more independent, active learning by students (Adhikari et al., 2017). Furthermore, better digital technology equipment in the classroom, students' access to digital technology, and internet infrastructure in the school were positively related to how teachers use digital technology in order to more frequently empower students' learning (Lucas, Bem-Haja, Siddiq, Moreira, & Redecker, 2021).

However, Sailer, Murböck, and Fischer (2021) found that the digital technology equipment in a school (operationalised as the availability of different types of digital technology devices and teachers' satisfaction with the digital technology equipment) was not significantly positively related to either the frequency of teaching with digital technology or the four ICAP digital learning activities.

2. The present study and research questions

With this study, we aimed to replicate and extend Sailer, Murböck and Fischer's (2021) study that investigated relationships of teachers' basic digital skills, technology-related teaching skills, and digital technology equipment with the frequency of teaching with digital technology and teachers' initiation of digital learning activities. By doing so, we intended to take a step towards developing a comprehensive model for systematically defining and measuring factors for digital teaching and learning in schools.

We expanded Sailer, Murböck, and Fischer's (2021) study in three ways, based on C♭ and current empirical research. First, for digital technology equipment, we distinguished between teachers' digital school equipment and students' mobile digital school equipment. Teachers' digital school equipment refers to digital technology devices provided by the school, of which there is typically only one device (e.g., projector) in the classroom. Such a device is then typically used by only one person, usually the teacher. By contrast, students' mobile digital school equipment refers to digital technology devices provided by the school, of which there are typically several available in the classroom, and thus, they can be used by several people (e.g., a tablet for each student). These devices are more in line with the 1:1 approach and the concept of mobile digital technology devices and the differentiation of digital technology equipment in C♭. Second, we supplemented the digital school equipment with personal digital technology devices that teachers (BYOD teachers) and students (BYOD students) bring to school, in line with the BYOD approach and C♭. Third, we included internet speed and school support for digital technology integration as new potential factors. By making these three changes, we aimed to cover more of the factors of C♭ and obtain a more precise picture of teachers' use of digital technology for teaching and learning and the factors associated with it.

We used data from a trend study conducted in 2017 and 2019. Sailer, Murböck, and Fischer (2021) used data from the measuring point in 2017 while we used data from the measuring point in 2019. Both studies used cross-sectional data and surveyed representative samples of teachers from the federal state of Bavaria, Germany.

We investigated the following two research questions:

RQ1. To what extent are teachers' technology-related skills, school support, teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed related to the frequency of teaching with digital technology?

First, we hypothesised that both teachers' basic digital skills (Hatlevik, 2017; Sailer, Murböck, & Fischer, 2021; Sundqvist et al., 2021) and technology-related teaching skills (Drossel et al., 2017; Jung et al., 2019) are positively related to the frequency of teaching with digital technology (H1.1). Although Sailer, Murböck, and Fischer (2021) did not find a positive relationship between teachers' technology-related teaching skills and the frequency of teaching with digital technology, we still assume this due to the majority of other studies that found a positive relationship. Second, though results on school support in the secondary school context have been somewhat inconsistent, multiple studies have indicated a positive relationship with the frequency of teaching with digital technology (Atman Uslu & Usluel, 2019; Hsu & Kuan, 2013). Additionally, in the higher education context, a positive relationship has been more consistently identified (Lohr et al., 2021). Therefore, we hypothesised that school support is positively related to the frequency of teaching with digital technology (H1.2).

Third, prior research has shown a positive relationship between an availability of digital technology equipment in schools and internet speed with the frequency of teaching with digital technology (Drossel et al., 2017; European Commission, 2019; Sauers & McLeod, 2018). Thus, we hypothesised that teachers' digital school equipment (H1.3), students' mobile digital school equipment (H1.4), BYOD teachers (H1.5), BYOD students (H1.6), and internet speed (H1.7) are positively related to the frequency of teaching with digital technology. Although Sailer, Murböck, and Fischer (2021) did not find support for a positive relationship between digital school equipment and the frequency of teaching with digital technology, our differentiation between teachers' digital school equipment and students' mobile digital school equipment leads us to the hypothesis presented above.

RQ2. To what extent are teachers' technology-related skills, school support, teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed related to teachers' initiation of digital learning activities?

First, regarding teachers' technology-related skills, we hypothesised that, as in the study we replicate, basic digital skills are positively related to passive, active and interactive digital learning activities (Sailer, Murböck, & Fischer, 2021), and additionally constructive digital learning activities (Quast et al., 2021; Vejvoda et al., 2024). Thus, basic digital skills are expected to be a necessary prerequisite for teachers initiating all four types of digital learning activities (H2.1).

Technology-related teaching skills, also seem important for initiating the whole spectrum of digital learning activities, particularly the more sophisticated digital learning activities (Sailer, Murböck, & Fischer, 2021; Sailer, Stadler, et al., 2021). We, thus, hypothesised that teachers' technology-related teaching skills show the strongest positive relationship with the initiation of interactive, followed by constructive, active, and passive digital learning activities (H2.2).

Second, research on the relationship between school support and teachers' initiation of digital learning activities is limited. However, based on prior research (Quast et al., 2021) and the aforementioned positive relationships with the frequency of digital teaching, it can be assumed that school support is important for teachers to cognitively activate students. Further, results from the higher education context indicate that adequate school support is particularly important for teachers' ability to initiate more sophisticated digital learning activities (Lohr et al., 2021). Thus, we hypothesised that school support is positively related to all four types of digital learning activities, but more strongly to the more sophisticated constructive and interactive digital learning activities rather than to the passive and active digital learning activities (H2.3).

Third, teachers' digital school equipment reflects the state of digital technology devices that the teacher is more likely to use alone, as they typically only have one of these devices available in the classroom. Thus, this probably leads to more teacher-centred lessons. By contrast, prior research has indicated that when more digital technology equipment is available to students in the classroom, being closer to mobile learning and a 1:1 approach, more student-centred, active learning takes place (Harper & Milman, 2016; Islam & Grönlund, 2016; Lucas et al., 2021; Song, 2014). Therefore, we hypothesised that having more digital technology equipment available to teachers – via teachers' digital school equipment, BYOD teachers, or both – leads to teachers initiating more passive digital learning activities (H2.4). In contrast, we hypothesised that having more digital technology equipment available to students—via students' mobile digital school equipment, BYOD students, or both—leads to teachers initiating more active, constructive, and interactive digital learning activities, that fall under active learning (Chi et al., 2018); H2.5). Additionally, we hypothesised that more BYOD by students leads to teachers initiating less passive digital learning activities (H2.6), as teachers may move away from teacher-centred lessons, as students become more self-regulated in their learning through BYOD (Adhikari et al., 2017).

Finally, we hypothesised that internet speed is positively related to all four types of digital learning activities, as it can be seen as a basis for effective digital teaching and learning (Brečko et al., 2014; Lucas et al., 2021; H2.7).

3. Method

3.1. Sample

We used a representative sample of $N = 407$ teachers in public secondary schools in the federal state of Bavaria, Germany. To ensure representativeness, the sample was randomly selected based on official and public reference data according to the administrative districts in Bavaria and the three types of secondary schools: lower track secondary school (Mittelschule*)*, middle track secondary school (Realschule) and high-track secondary school (Gymnasium). This procedure was identical to Sailer, Murböck, and Fischer's (2021) study. A total of 48.9% of teachers identified as female and 51.1% as male. On average, teachers were 48 years old ($M = 48.17$; $SD = 10.40$; 9.3% did not answer) and had been in service for a mean duration of 20 years ($M = 20.21$; $SD = 9.99$; 10.6% did not answer). Teachers reported teaching with digital technology for an average of 15 years ($M = 14.98$; $SD = 7.12$; 18.2% did not answer). Teachers taught in the schools of all seven administrative districts of Bavaria and in all three types of secondary schools. Demographically, the sample in this study was very similar to Sailer, Murböck, and Fischer's (2021) sample. Demographic data from both studies are provided in the OSF repository [https://osf.io/9wfrs/].

3.2. Procedure and instrument

The survey was administered using structured, computer-assisted telephone interviews that took about 23 min on average. The telephone survey was administered by the institute GMS Dr. Jung GmbH between mid-November 2019 and the end of December 2019, before the COVID-19 pandemic. Overall, the survey contained 24 questions, of which we used a subset relevant to this study's variables. This subset of questions is available at [https://osf.io/9wfrs/].

3.3. Measures

We assessed different teacher-related and school-related variables as potential factors influencing teachers' frequency of teaching with digital technology and their initiation of the four types of digital learning activities. All variables were measured based on teachers' self -reports.

3.3.1. Measurement of teachers' frequency of teaching with digital technology and initiation of digital learning activities

We measured teachers' frequency of teaching with digital technology and their initiation of digital learning activities identically to Sailer, Murböck, and Fischer's (2021) study. For the frequency of teaching with digital technology, we asked teachers to estimate the proportion of lessons in which they teach with digital technology. We measured teacher-initiated digital learning activities as the ratio of the respective digital learning activity to the frequency of teaching with digital technology. To obtain this ratio, in Step 1, we presented teachers with four brief descriptions for each digital learning activity. With one item per description, we asked them to rate the frequency with which they use digital technology in a typical lesson in a manner similar to the description, on a 5-point Likert scale, ranging from "never" (0) to "very often" (4). In Step 2, we calculated the proportions of each digital learning activity by dividing the Likert score for each activity by the sum score of all digital learning activities and then multiplied the resulting score by the frequency of teaching with digital technology.

3.3.2. Measurement of teachers' technology-related skills and school support for digital technology integration

We measured teachers' basic digital skills, teachers' technology-related teaching skills, and school support for digital technology integration as latent variables. An overview of the items used for these three variables, their descriptive results, and abbreviations are presented in Table 1. The exact item wordings can be found at [https://osf.io/9wfrs/].

Table 1
The abbreviation, sample size (*N*), mean (*M*), standard deviation (*SD*), minimum (*Min.*), and maximum (*Max.*) for single items used for the three latent variables, basic digital skills, technology-related teaching skills, and school support.

	abbreviation	*N*	*M*	*SD*	*Min.*	*Max.*
Basic digital skills						
General digital technology use	bds1	404	4.86	.40	3	5
Research via digital technology	bds2	402	4.82	.41	3	5
Communication via digital technology	bds3	404	4.57	.62	2	5
Collaboration via digital technology	bds4	394	3.70	1.15	1	5
Production of content via digital technology	bds5	400	4.06	.94	1	5
Technology-related teaching skills						
Technological knowledge	tk	392	4.16	.94	1	5
Technological pedagogical knowledge	tpk	388	4.19	.79	2	5
Technological pedagogical content knowledge	tpack	398	4.28	.65	3	5
Technological content knowledge	tck	398	4.20	.74	2	5
Planning digital technology use in class	pl	402	2.70	1.04	1	5
Implementing digital technology use in class	impl	398	3.13	.99	1	5
Evaluation of digital technology use in class	eval	398	3.19	1.13	1	5
Sharing experiences of digital technology use in class	shar	399	2.98	1.35	1	5
School support						
Further training about 'digital technology' at the request of the principal	supp1	407	.40	.49	0	1
Support of the principal	supp2	405	4.50	.81	1	5
Pedagogical support	supp3	396	3.87	1.07	1	5
External appearance of the school	supp4	396	3.74	1.02	1	5

Note. All items were assessed on a 5-point Likert scale, ranging from "never" (1) to "very often" (5) for items regarding basic digital skills and the skill component of technology-related teaching skills, and ranging from "not at all true" (1) to "completely true" (5) for the knowledge component of technology-related teaching skills, and for school support. The exception was the item 'further training about 'digital technology' at the request of the principal', which was measured on a dichotomous response scale that was scored as either 0 (yes, I have taken part in further training about 'digital technology' at the principal's request) or 1 (no, I have not taken part in further training about 'digital technology' at the principal's request).

We assessed the fit of the measurement models for these three variables with confirmatory factor analysis (CFA). We computed the analyses in MPlus 8.6. (Muthen & Muthen, 2017) using weighted least squares means and variance adjusted (WLSMV) estimation for ordered nonnormal categorical data (Finney & DiStefano, 2006). In contrast to Sailer, Murböck, & Fischer's (2021) study, we changed the estimator from MLR to WLSMV, as it provided a better fit for our Likert-scaled items (Morata-Ramírez & Holgado-Tello, 2012). We used common fit indices and cut-off values to assess the fit of each measurement model, Chi Square $p \geq .05$, $CFI \geq .95$, $SRMR < .08$, $RMSEA \leq .06$ (Hu & Bentler, 1999; Kline, 2023). Additionally, the item factor loadings needed to be positive to be included in the measurement model. We further examined the modification indices for each measurement model. All changes to our measurement models had to be theoretically justifiable (Xia & Yang, 2019). Table 2 shows the model fit for the final measurement models of teachers' technology-related skills and school support. Fit indices of the measurement models with unsatisfactory fit can be found at [https://osf.

Table 2
Chi-square test (χ2, *df*, and *p*), confirmatory fit index (*CFI*), standardised root mean square residual (*SRMR*), and root mean square error of approximation (*RMSEA*) for the measurement and structural models.

	χ2	*df*	*p*	*CFI*	*SRMR*	*RMSEA*
Measurement models						
Basic digital skills	5.34	5	.38	.95	.03	.01
Technology-related teaching skills	22.35	18	.22	.99	<.001	.02
School support	.3	1	.59	1	.01	< .001
Structural models						
Frequency of teaching with digital technology	242.65	229	.26	.98	.06	.01
Digital learning activities	297.62	271	.13	.97	.06	.02

Note. Fit criteria for all measurement and the structural models were Chi Square p ≥ .05, CFI ≥.95, SRMR <.08, RMSEA ≤.06.

io/9wfrs/].

We measured basic digital skills with Sailer, Murböck & Fischer's (2021) scale that is based on KMK (2017) and covers teachers' instrumental basic digital skills with six self-assessment items rated on a 5-point Likert scale, ranging from "never" (1) to "very often" (5). For the initial model, the model fit was already satisfactory, but we had to remove one item ("Learning via digital technology", see [https://osf.io/9wfrs/]) due to a negative loading. After this modification, all factor loadings were positive, and the final measurement model still had a satisfactory fit (see Table 2). We measured technology-related teaching skills with eight self-assessment items by Sailer, Murböck, and Fischer (2021) on a 5-point Likert scale. The scale included facets from the TPACK framework (Mishra & Koehler, 2006), with response answers ranging from "not at all true" (1) to "completely true" (5), and items regarding the four teaching phases, with response answers ranging from "never" (1) to "very often" (5). The fit of the initial model was unsatisfactory. Thus, on the basis of theoretical reasoning, we added the residual covariance of "planning digital technology use in class" with "implementing digital technology use in class", as these two teaching phases are interconnected because they are both closely related to the realization of teaching with digital technology (DCB, 2017; Sailer, Schultz-Pernice, & Fischer, 2021). The same residual covariance was also added in a measurement model of technology-related teaching skills using the same items, but in the context of higher education (Lohr et al., 2021). In a further step, we added the residual covariance of "evaluation of digital technology use in class" with "sharing experiences of digital technology use in class", which had the highest modification index. After these two modifications, the model fit was satisfactory (see Table 2).

Finally, we assessed school support for digital technology integration with five items: support from the principal, sufficient technical and pedagogical support in the school, and the importance of digital technology for the school's external appearance (all measured on a 5-point Likert scale, ranging from "never" (1) to "very often" (5)), plus whether teachers had taken part in further training on the topic of 'digital technology' at the request of the principal (dichotomous response scale). The initial model fit was not satisfactory, and the item regarding technical support (see [https://osf.io/9wfrs/]) had a negative loading. Thus, we removed the item and added the residual covariance of support of the principal and pedagogical support in a further step. Then, the final measurement model had satisfactory fit, and all factor loadings were positive (see Table 2).

3.3.3. *Measurement of digital technology equipment and internet speed*

We measured four variables that were related to the digital technology equipment available in a school (teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students), and internet speed. Table 3 presents an overview of the items used for these variables. Our measures of teachers' digital school equipment and students' mobile digital school equipment were similar to Sailer, Murböck & Fischer's (2021) study. Following the notion of integrating mobile devices, we asked teachers if certain digital technology devices were accessible in every classroom at their school for both items. We thus excluded digital technology devices that were only located in central rooms (e.g., computer labs). We included the following six types of digital technology devices as examples of teachers' digital school equipment: PCs, laptops, projectors, smartboards, document cameras, and DVD players. The rationale behind this allocation was that usually only one of each of these types of devices is available in a classroom, and it is then most likely going to be used by only one person, who is therefore most likely going to be the teacher. For students' mobile digital school equipment, we included four types of digital technology devices: tablets, digital photo and video cameras, smartphones, and interactive tables. These devices follow the notion of the 1:1 approach, and thus, it is likely that several of each of these devices are available in a classroom, and then several people (i.e., students) can use them in class. For each of the two variables, we created a sum score across the various digital technology devices.

Table 3
The sample size (*N*), mean (*M*), standard deviation (*SD*), minimum (*Min.*), and maximum (*Max.*) for manifest variables coverage teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed.

	N	M	SD	Min.	Max.
Teachers' digital school equipment	407	3.33	1.14	0	6
Students' mobile digital school equipment	406	.55	.69	0	3
BYOD teachers	407	.92	.27	0	1
BYOD students	407	.84	.36	0	1
Internet speed	403	3.28	1.39	1	5

Note. Teachers' digital school equipment could range from 0 (no digital teacher technology devices available in every room) to 6 (six types of digital teacher technology devices available in every room). Students' mobile digital school equipment could range from 0 (no digital student technology devices available in every room) to 4 (four types of digital student technology devices available in every room). BYOD teachers and BYOD students were scored as either 0 (teachers or students did not bring at least one of four personal digital technology devices to school for lessons) or 1 (teachers or students did bring at least one of four personal digital technology devices to school for lessons). Internet speed was assessed on a 5-point Likert scale, ranging from "not at all true" (1) to "completely true" (5).

To assess BYOD teachers and BYOD students we asked teachers about four different types of digital technology devices, namely laptop, tablet, digital photo and video camera, and smartphone. For each type of device, they had three answer options: they could indicate whether a) they, b) their students or c) neither did bring the device to school from home specifically for lessons. Multiple answers were possible for the first two response options. Then, we created two dichotomous variables. All teachers or students that brought at least one of the devices were scored as 1, otherwise as 0 (see Table 3).

Finally, we assessed internet speed on a 5-point Likert scale, ranging from "not at all true" (1) to "completely true" (5), by asking teachers whether the internet at their school is fast enough to use it in any way they deem useful in the classroom.

3.4. *Statistical analyses*

To address RQ1 and RQ2, we used a structural equation modelling (SEM) approach in Mplus 8.6. (Muthen & Muthen, 2017). For RQ1, we computed an SEM with the frequency of teaching with digital technology as the outcome variable. For RQ2, we computed an SEM with the four types of digital learning activities as outcome variables. We used the same eight factors in both SEMs: basic digital skills, technology-related teaching skills, school support, teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed. In both SEMs, we fixed the factor loadings and residual covariances of the three latent factors (i.e., basic digital skills, technology-related teaching skills, and school support) to those previously estimated in the measurement models via CFA. We did so to avoid interpretational confounding (see Anderson & Gerbing, 1988; Bainter & Bollen, 2014). We allowed the three latent factors to correlate, and we standardised all coefficients before reporting. In all analyses, we dealt with missing data with pairwise deletion.

4. Results

Descriptive results of the frequency of teaching with digital technology and teachers' initiation of the four types of digital learning activities are reported in Table 4. An overview of all results of the two structural equation models can be found at [https://osf.io/9wfrs/].

4.1. Relationships of teachers' technology-related skills and school-related factors with the frequency of teaching with digital technology

To answer RQ1, we examined the relationships between teachers' basic digital skills and technology-related teaching skills, school support, teachers' digital school equipment and students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed with the frequency of teaching with digital technology. A total of $N = 363$ teachers were included in the analysis. The SEM showed good fit to the data (see Table 2) and is visualised in Fig. 1.

The results for RQ1 showed that teachers' basic digital skills ($p = .421$) and technology-related teaching skills ($p = .141$) were not statistically significantly related to the frequency of teaching with digital technology, thus not supporting H1.1. Similarly, school support was not statistically significantly related to the frequency of teaching with digital technology ($p = .404$), failing to support H1.2. Neither teachers' digital school equipment ($p = .221$) nor students' mobile digital school equipment ($p = .418$) was statistically significantly related to the frequency of teaching with digital technology, contradicting H1.3 and H1.4. By contrast, BYOD teachers was statistically significantly and positively related to the frequency of teaching with digital technology ($\beta = .11$, $p = .032$), with a small effect size. This result was consistent with H1.5. BYOD students also showed a statistically significant, but negative relationship with the frequency of teaching with digital technology ($\beta = -.15$, $p = .004$), with a small effect size, which was not in support of hypothesis H1.6. Finally, internet speed ($p = .865$) was not statistically significantly related to the frequency of teaching with digital technology, and therefore, our results did not support H1.7. Overall, the SEM explained 4% of the variance in the frequency of teaching with digital technology.

Table 4
The minimum (Min.), maximum (Max.), mean (M), standard deviation (SD), and sample size (N) for the frequency of teaching with digital technology (in %) and teachers' initiation of passive, active, constructive, and interactive digital learning activities.

	N	M	SD	Min.	Max.
Frequency of teaching with digital technology	396	52.4%	23.86%	10%	100%
Passive digital learning activities	385	17.1	10.29	1	52.5
Active digital learning activities	383	12.3	8.86	0	50
Constructive digital learning activities	384	12.6	7.85	0	38
Interactive digital learning activities	381	11.9	7.99	0	50

Note. The frequency of teaching with digital technology could range from 0% (teachers taught with digital technology in none of their lessons) to 100% (teachers taught with digital technology in all of their lessons). The four types of digital learning activities were measured as the ratio of the respective digital learning activity to the frequency of teaching with digital technology and could range from 0% to 100%.

4.2. Relationships of teachers' technology-related skills and school-related factors with teacher-initiated digital learning activities

To investigate RQ2, we examined how teachers' basic digital skills and technology-related teaching skills, school support, teachers' digital school equipment, BYOD teachers, students' mobile digital school equipment, BYOD students, and internet speed were related to the four types of digital learning activities. The descriptive results for these four outcome variables are presented in Table 4. Data of $N = 346$ teachers were included in the analysis. The SEM showed good fit to the data (see Table 2) and is visualised in Fig. 2.

The results showed that basic digital skills were not statistically significantly related to passive ($p = .259$), active ($p = .183$), constructive ($p = .599$), or interactive digital learning activities ($p = .076$), thus not supporting H2.1. Technology-related teaching skills were statistically significantly and positively related to active digital learning activities ($\beta = .28$, $p = .002$) and constructive digital learning activities ($\beta = .18$, $p = .036$), with a small effect size. However, they were not statistically significantly related to passive ($p = .367$) or interactive ($p = .201$) digital learning activities, thus the results partially support H2.2. As expected, school support was statistically significantly and positively related to interactive digital learning activities ($\beta = .19$, $p = .039$), with a small effect size. School support was, however, not statistically significantly related to passive ($p = .988$), active ($p = .215$), or constructive digital learning activities ($p = .558$), thus partially supporting H2.3.

In terms of teachers' digital technology equipment in the classroom, we hypothesised that more digital technology equipment for teachers overall (provided by the school, BYOD, or both) leads to teachers initiating passive digital learning activities more frequently. The results showed that BYOD teachers was statistically significantly and positively related to passive digital learning activities ($\beta = .11$, $p = .028$), with a small effect size, whereas teachers' digital school equipment was not statistically significantly related to passive digital learning activities ($p = .353$). Thus, H2.4 was partially supported by these results.

Regarding students' digital technology equipment in the classroom we hypothesised that more digital technology equipment for students overall (provided by the school, BYOD, or both) leads to teachers initiating more active, constructive, and interactive digital learning activities. The results did not support this hypothesis (H2.5): Students' mobile digital school equipment was not statistically significantly related to active ($p = .178$), constructive ($p = .735$), or interactive digital learning activities ($p = .127$). Similarly, BYOD students was not statistically significantly related to constructive ($p = .075$) or interactive digital learning activities ($p = .826$). We even found a result in the opposite direction of our expectations, as BYOD students was statistically significantly and negatively related to active digital learning activities ($\beta = -.15$, $p = .001$), with a small effect size. Further, we hypothesised that BYOD students shows a statistically significant and negative relationship with passive digital learning activities (H2.6), which was supported by the results ($\beta = -.14$, $p = .002$), and had a small effect size.

Finally, we hypothesised that internet speed is statistically significantly and positively related to all four types of digital learning activities (H2.7). The results partially supported this hypothesis, as internet speed was statistically significantly and positively related to interactive digital learning activities ($\beta = .12$, $p = .013$), with a small effect size.

Overall, this SEM explained 3% of the variance in passive digital learning activities, 11% in active digital learning activities, 4% in constructive digital learning activities, and 8% in interactive digital learning activities.

5. Discussion

5.1. Summary of the main results

In this study, we aimed to identify teacher-related and school-related

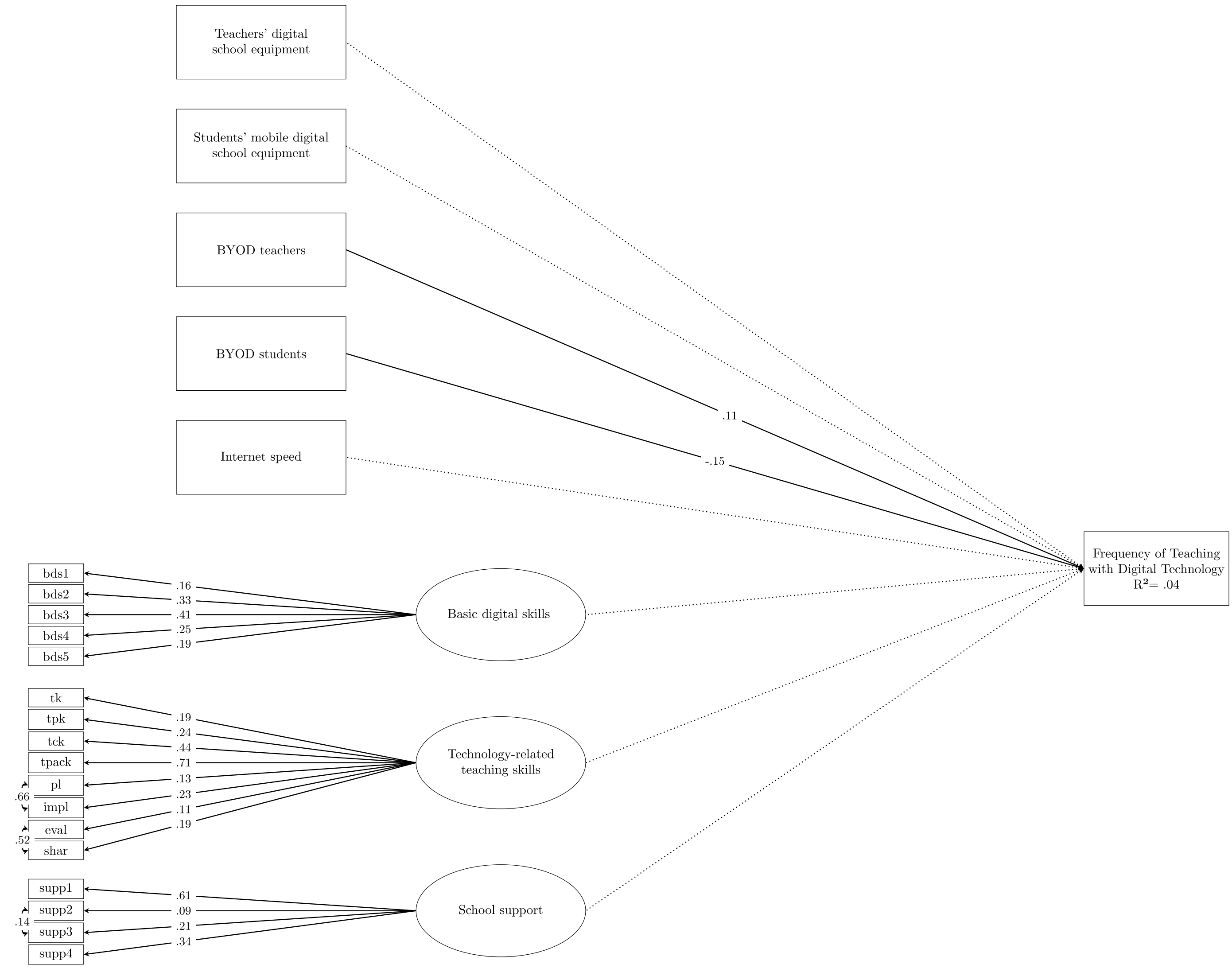

Fig. 1. The structural equation model (SEM) with frequency of teaching with digital technology as the outcome variable and basic digital skills, technology-related teaching skills, school support, teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed as factors. Circles represent latent variables, and rectangles represent manifest variables. Lines indicate significant relationships, and dotted lines indicate nonsignificant relationships. The given values are beta values.

factors that are associated with two outcomes: the frequency of teaching with digital technology and teachers' initiation of four types of digital learning activities in 2019. We aimed to replicate and extend results from Sailer, Murböck & Fischer's (2021) study, which was conducted in 2017–2 years before our study. Furthermore, drawing upon C♭, we wanted to take a step towards developing a comprehensive model for the school context, which would facilitate a more systematic investigation of the interplay of factors for digital teaching and learning in future research.

Three key points emerged that should be considered when developing such a model. First, unlike teachers' basic digital skills, teachers' technology-related teaching skills were statistically significantly and positively related to specific types of active learning in students. Second, the role of the digital technology equipment available in a school requires a differentiated view, based on who provides the digital technology device: Teachers' and students' BYOD play more important roles than the digital technology equipment provided by the school for teachers' initiation of digital learning activities. Lastly, school support for digital technology integration and internet speed were statistically significantly and positively related to interactive digital learning activities, the most sophisticated of the types of digital learning activities. Overall, the model fits were good, partially supporting the generalisation of C♭ to the secondary school context. However, the proportion of variance explained by the factors of C♭ was relatively low.

5.2. The role of teachers' technology-related teaching skills

Regarding teachers' technology-related teaching skills, results showed that teachers' basic digital skills matter less than teachers' technology-related teaching skills in explaining teaching and learning with digital technology in the classroom. Teachers' basic digital skills were hardly related to more frequent or more effective digital teaching and learning, a finding that diverges from the results reported by Sailer, Murböck, and Fischer (2021), who found a positive relation, with a medium effect size. This finding also diverges from results from other research (Hatlevik, 2017; Lohr et al., 2021; Quast, Rubach & Lazarides, 2021; Sundqvist et al., 2021).

In accordance with Sailer, Murböck, and Fischer (2021), teachers' technology-related teaching skills were positively related to students' active learning and more sophisticated forms of digital learning activities. We replicated the finding of a positive relation of teachers' technology-related teaching skills with constructive digital learning

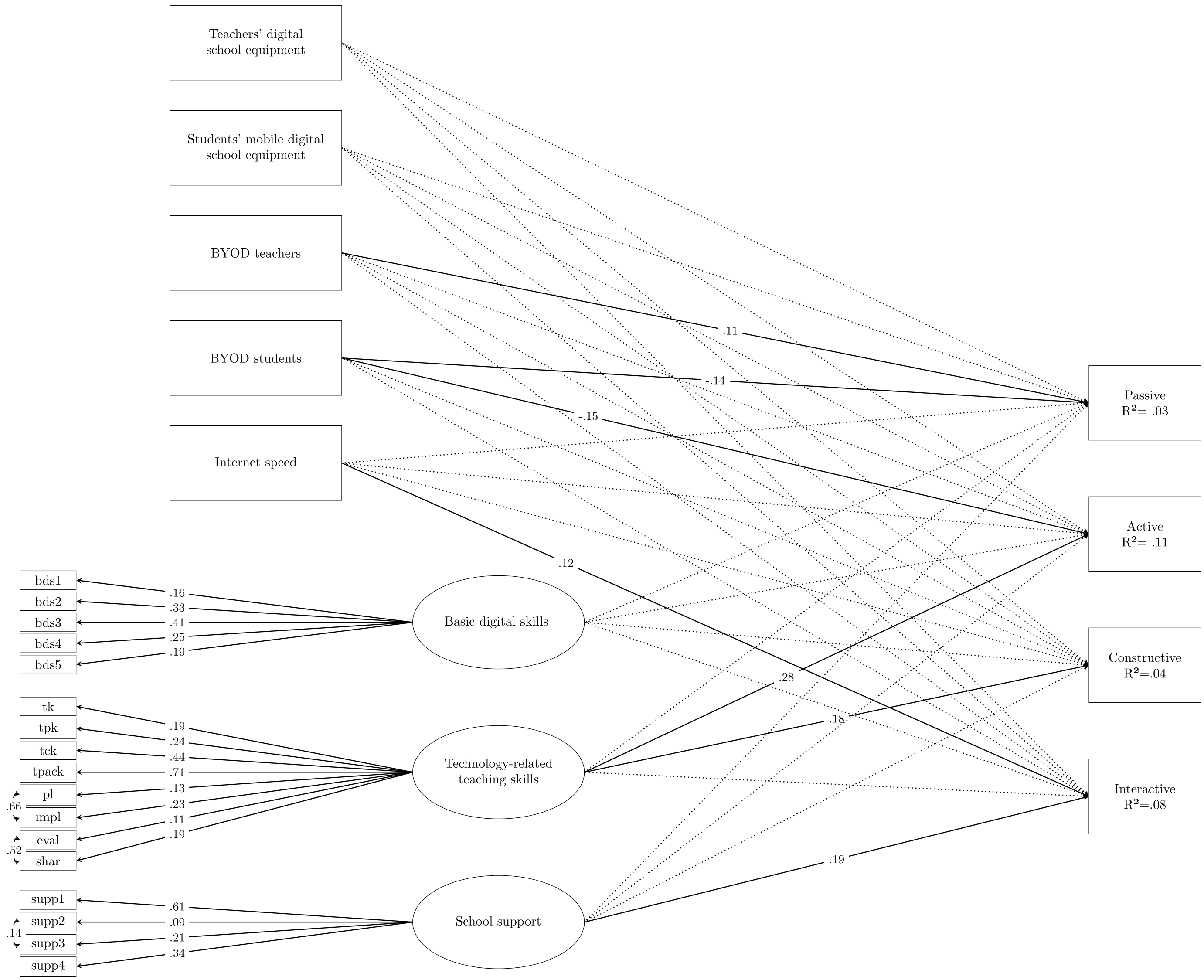

Fig. 2. Structural equation model (SEM) with the four types of digital learning activities as outcome variables. Factors are basic digital skills, technology-related teaching skills, school support, teachers' digital school equipment, students' mobile digital school equipment, BYOD teachers, BYOD students, and internet speed. Circles represent latent variables, and rectangles represent manifest variables. Lines indicate significant relationships, and dotted lines indicate nonsignificant relationships. The given values are beta values.

activities, though with a small effect size compared to a medium effect size in Sailer, Murböck, and Fischer (2021). Beyond their findings, we also found a positive association of teachers' technology related teaching skills with active digital learning activities.

The limited role of basic digital skills might be explained by the fact that teachers in our sample rated their basic digital skills consistently high in general (see Table 1) compared to Sailer, Murböck, and Fischer's (2021) study. This tendency likely compromised our ability to detect changes in the frequency of teaching with digital technology and digital learning activities. On the one hand, in-service professional development initiatives (e.g., on digital technology that the federal state of Bavaria implemented in 2019; mebis-Redaktion, 2020) may have contributed to the improved and overall high basic digital skills of teachers. On the other hand, teachers' self-assessment may have been prone to biases, thus leading to a ceiling effect in our measurement of basic digital skills (Drummond & Sweeney, 2017; Siddiq et al., 2016). One of the biases might be overconfidence, as teachers may have considered their basic digital skills to be very good due to the prevalence of their use of digital technology in everyday life. A second bias might be social desirability, as teachers may have felt pressure to report well-developed basic digital skills due to increased standards for digitalisation in their schools. These potential biases point to the importance of using objective measures when measuring technology-related skills in future research. In summary, we can make only cautious statements about teachers' basic digital skills. They might be needed as a basis but are not sufficient for effective digital teaching and learning in schools. Thus, if the goal is to foster students' active learning and complex skills, it seems important to systematically focus on teachers' technology-related teaching skills.

5.3. *The role of digital technology equipment*

Regarding school-related factors, we found interesting differences when differentiating between the digital technology equipment provided by the school and the personal digital technology devices that teachers and students bring to school themselves (BYOD). On the one hand, the digital technology equipment provided by the school for teachers and students to use was not related to the frequency of teaching with digital technology or teachers' initiation of digital learning activities. Thus, we replicated Sailer, Murböck & Fischer's (2021) result, although we looked at digital school equipment in a more differentiated way in the current study.

On the other hand, we found interesting results about the personal digital technology devices that teachers and students bring to school. As expected, BYOD by teachers was positively related to a more passive-receptive teaching approach and to teachers using digital technology more often in their teaching. One reason for this finding could be that, typically, there is only one digital technology device that the teachers bring to school, and therefore, only one person at a time can use it meaningfully in class, which is most likely the teacher.

By contrast, BYOD by students was related to a less passive-receptive teaching approach as expected, but unexpectedly, it was also related to a lower frequency of teaching with digital technology. A further unexpected result was that teachers also initiated less active digital learning activities the more students brought their own digital technology devices to class. The reduction in frequency when students brought their own digital technology devices might be due to several points that might have led to teachers' underestimation of actual usage. First, teachers might have had a biased view because when students bring their own devices, teachers are less directly involved with the use of the digital technology, as they do not control the devices themselves during class. Thus, they might not have perceived students' use of their BYOD devices as technology use. Second, as BYOD gives students more ownership over their learning, teachers may not notice all instances of BYOD use by students in class, as it is less visible (Adhikari et al., 2017). Further, specific challenges associated with BYOD, such as students' being more easily disengaged, access and equity issues, compatibility issues and varying levels of basic digital skills in students can make it difficult for teachers to integrate BYOD effectively into their teaching practice (Adhikari et al., 2017; Santos, 2020).

As a result of a lower frequency of teaching with digital technology, the proportions of the individual learning activities should also go down, as the frequency is divided among the four types of digital learning activities. We indeed observed this trend for passive and active digital learning activities, which are related to more shallow learning processes in students. However, we did not observe this reduction for the constructive and interactive digital learning activities, which are related to deep learning processes. Thus, these two types of digital learning activities have actually become proportionately larger due to BYOD by students.

Overall, these results show that the digital technology equipment provided by the school did not play the crucial role in more effective digital teaching and learning that is often attributed to it in research and political discussions (European Commission, 2019; OECD, 2020). Instead, our results generally point towards the systematic inclusion of BYOD in future studies and adopting a differentiated perspective on who, teachers or students, are bringing digital technology devices with them. Our study indicates that who brings the device can determine the extent to which digital technology is used for active learning in lessons.

5.4. *The role of school support and internet speed*

School support and internet speed seem to be promising factors related to teachers' initiation of interactive digital learning activities in which students work collaboratively. As interactive digital learning activities are technically and pedagogically more demanding than the other three types of digital learning activities for teachers to design and implement effectively due to their collaborative nature, adequate support structures in school are probably beneficial. Similarly, to ensure that several students can work together productively when using digital technology devices, a fast internet connection is of great importance. This finding is in line with Lucas et al. (2021), who found that a better internet connection led to teachers more frequently empowering students, including actively engaging students, which can encompass engaging them in interactive digital learning activities (Chi et al., 2018). Thus, the particular characteristics of interactive digital learning activities may explain why we found effects of school support and internet speed for this type but not for the less sophisticated types of digital learning activities. These results go beyond Sailer, Murböck, and Fischer's (2021) findings, as both school support and internet speed were newly examined as factors in the present study. Further, our study makes an important contribution to the state of research, as not much previous research has been devoted to exploring how school support and internet speed are related to students' cognitive activation. Thus, including both school support and internet speed in future research seems important for assessing whether the findings from our study are generalisable. As a practical implication, dedicated school support and fast internet speed seem to be promising levers, if the aim is to digitally support students' collaborative learning.

5.5. *Limitations*

We also need to address some of our study's limitations. First, our results are based on teachers' self-assessments, which led to possible biases in the assessment of basic digital skills. In general, self-assessments are commonly used with teachers, especially in large-scale studies (Fraillon et al., 2020), as they are inexpensive and allow for large sample sizes. However, especially for teachers' technology-related skills, objective measurements should be included more frequently in the future (Siddiq et al., 2016). Second, due to the cross-sectional design of the present study, we cannot infer causality, even though we built on a theoretical model specifying causal relationships. We replicated previous findings and identified new associations between teacher- and school-related variables and digital teaching and learning. These findings are relevant for future research but should nevertheless be investigated with longitudinal study designs. Third, as our study results are representative of teachers in Bavaria, Germany, they are likely to generalise to countries and regions with similar conditions in their educational system. One prerequisite is that the digital technology use in the classroom has already been established to a certain extent. Additionally, similar contexts would be characterised by state demands and support measures to systematically promote digital teaching and learning in schools, such as funding schemes, media strategies, and professional development. Lastly, although our analyses generally accounted for only a relatively low proportion of variance in the frequency of teaching with digital technology and the four types of digital learning activities, we argue that these values are acceptable in study designs such as ours because we did not conduct an intervention study, and the possible set of factors of influence is large.

To explain more variance, it might be helpful to revisit C♭ and the factors contained therein, such as teachers' technology related attitudes: the perceptions and expectations that teachers have towards the use of digital technology in class can foster or hinder to what extent and how they use digital technology (Backfisch, Lachner, Hische, Loose, & Scheiter, 2020; Hsu & Kuan, 2013). Another important area of C♭ that has not been considered in the present study concerns the students, namely their set of technology-related knowledge, skills and attitudes. As learning outcomes, these are, on the one hand, the benchmark of effective digital teaching and learning. On the other hand, students' knowledge, skills, and attitudes can be considered prerequisites for how easily and effectively teachers can initiate different types of digital learning activities (Scheel, Vladova, & Ullrich, 2022). Furthermore, to explain more variance, it might be useful to examine the digital technology equipment available at the school and internet speed as moderators of the relationships between teachers' skills and digital teaching and learning, or to calculate non-linear relationships. Possibly, this would more appropriately reflect their role as a necessary but not sufficient condition for successful digital teaching and learning.

5.6. *Conclusions*

In the present study, we replicated and substantially extended Sailer, Murböck, and Fischer's (2021) study. In a sample of 407 school teachers, we identified five factors that appear to be important to consider systematically in an overarching theoretical model for digital teaching and learning in the (secondary) school context. First, teachers bringing their personal digital technology devices to class (BYOD) is positively related to teacher-centred teaching and learning, with students more often being exposed to passive digital learning activities. Second, students bringing their personal digital technology devices to class is related to teachers initiating less passive and active digital learning activities that are associated with shallow learning processes, and proportionally more constructive and interactive digital learning activities, that are associated with deeper learning processes. Third, we replicated Sailer, Murböck, and Fischer's (2021) finding that technology-related teaching skills are important for teachers to initiate different forms of active learning in students, especially those related to deep learning processes that are necessary for complex skill acquisition. Fourth and fifth, school support for technology integration and internet speed, the roles of which have not yet been clearly established in research, play significant roles in teachers' abilities to initiate more interactive digital learning activities that are related to the deepest form of students' cognitive activation and, thus, to the promotion of students' complex skills. Overall, we were able to partially validate the C♭-model (Sailer, Schultz-Pernice, & Fischer, 2021) in the school context.

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CRediT authorship contribution statement

Anne Lohr: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Michael Sailer:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing. **Matthias Stadler:** Formal analysis, Methodology, Writing – review & editing. **Frank Fischer:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that there are no conflicts of interest.

Data availability

Supplemental materials are available in OSF. Link is provided in the article.

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