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Transformational leadership for technology integration in schools: Empowering teachers to use technology in a more demanding way

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A B S T R A C T

The present study aims to investigate whether the transformational leadership practices of school principals support teachers in using digital technologies in a way that fosters students' engagement in cognitively demanding learning activities in class. To this end, teachers' positive beliefs about digital technology, their technical skills, the digital school infrastructure, and teachers' skills in teaching with digital technologies were investigated as relevant mediators of the relationship between transformational leadership and technology integration. Based on a survey of 2247 upper secondary education teachers in Switzerland, multilevel correlation and structural equation modeling analysis indicated that transformational leadership had a significant and positive impact on the digital school infrastructure, teachers' positive beliefs about digital technology, their technical skills, and their skills in teaching with digital technologies. In turn, all of these factors, except the digital school infrastructure, significantly and positively predicted higher levels of technology integration. These findings position principals' transformational leadership approaches as crucial in supporting teachers as key players in technology integration in the classroom.

1. Introduction

School leaders have come into the focus of research on technology integration in schools (Chiu, 2022; Dexter, 2018; Dexter & Richardson, 2020; Eickelmann, 2011; Fisher & Waller, 2013; Papaioannou & Charalambous, 2011; Shattuck, 2010). The study by McLeod and Richardson (2011) showed that the studies on technology leadership have focused on staff development, technology policies, and technology integration. Much has changed since McLeod and Richardson (2011) claimed that there was a lack of studies on technology leadership; many studies have since focused on leadership practices and technology integration. Moreover, educational leadership research has recently changed its focus from leader characteristics to leadership practices, which are activities reflecting the specific situation carried out by a person or group that has shared outcomes in mind (Leithwood, 2012, 2017). Various efficient leadership practices have been described in the literature. For example, a literature review by Hitt and Tucker (2016) identified five important domains of general leadership practices that leaders should enact to enhance students' achievement: establishing and conveying the vision, facilitating a high-quality learning experience for students, building professional capacity, creating a supportive

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organization for learning, and connecting with external partners. In a more recent systematic review, Grissom et al. (2021) reported four important areas of general leadership practices that foster students' achievement: engaging in instructional-focused interactions with teachers, establishing a productive school climate, promoting productive collaboration and professional learning communities, and the strategic management of personnel and resources.

Similarly, regarding fostering technology integration in schools, Dexter, Richardson, and Nash (2016) identified five key domains of effective technology leadership: vision, student learning, professional development and organizational change, support for the organization's learning, and external partnerships. These findings are supplemented and confirmed by Dexter and Richardson's (2020) more recent systematic literature review, which revealed five domains of technology leadership key practices for school leaders: establishing and conveying a vision, facilitating educational technology use for students, building professional capacity, creating a supportive organization, and connecting with external partners. Of these five domains, Dexter (2018) previously described three distinct core domains of leadership practices, the first being that principals should set directions by identifying a shared vision, creating a shared meaning, developing expectations, monitoring performance, and communicating the vision and goals. The second area of leadership practices involves developing the people by harnessing the power of individuals, developing groups of teachers, and leading by example. Third, principals develop the organization by building a collaborative culture, structuring the organization, allocating resources, and connecting to the wider environment. In performing these duties, headmasters positively influence the complex interplay of many enabling factors for technology integration in class (see Vermeulen, van Acker, Kreijns, & van Buuren, 2015; Vermeulen, Kreijns, van Buuren, & van Acker, 2017; Yamamoto & Yamaguchi, 2019). Beyond these leadership practices, which show many overlaps, there has been a discussion about leadership styles. Studies on leadership styles have attempted to describe how educational leaders enact different practices. Apart from the traditional distinction between top-down and bottom-up, or between direct or indirect styles of leadership, there have been more recent attempts to identify balanced approaches that combine these styles in a meaningful way (Daniëls, Hondeghem, & Dochy, 2019).

1.1. *Transformational leadership influencing technology integration*

A conceptual framework for a combined leadership style that shows close connections to the leadership practices described by Dexter (2018) is transformational leadership, since the key practices of this leadership behavior in schools are establishing and communicating a vision in a way that develops the organization and fosters collaboration between teachers and developing the people by approaching them individually and by setting a good example (see Anderson, 2017; Daniëls et al., 2019; Hitt & Tucker, 2016; Ottestad, 2013). Bass (1990) defined transformational leadership as including four key components: idealized influence (offering a sense of purpose and acting as a model of the change process), inspiration (informing employees about high expectations and communicating important aspects in a comprehensible manner), intellectual stimulation (fostering the employees' creativity, critical thinking, and problem-solving), and individual consideration (paying attention to each employee, coaching, and advising). To measure transformational leadership, scholars have differentiated these components into the following sub-aspects: vision (inspiration); staff development and supportive leadership (individual consideration); empowerment by fostering employees' involvement in decision-making processes, collaboration, and innovative thinking (intellectual stimulation); leadership by example; and charisma (idealized influence, Carless, Wearing, & Mann, 2000; Podsakoff, MacKenzie, Moorman, & Fetter, 1990). However, beyond leadership behavior, Bass (1990) and Carless et al. (2000) emphasized the role of charismatic leader figures, whereas today's research on leadership focuses on leadership practices (see Dexter, 2018; Dexter & Richardson, 2020; Grissom et al., 2021; Hitt & Tucker, 2016; Leithwood, 2012, 2017). This shift is also visible in the research on transformational school leadership, as reflected by recent literature reviews that stress even more leadership behaviors, such as communicating a vision, motivating teachers toward achievement, approaching teachers individually, and being a good example in the change process (see Anderson, 2017; Daniëls et al., 2019; Hitt & Tucker, 2016) that align with core practices described for effective technology integration in schools (see Dexter, 2018; Dexter & Richardson, 2020; Dexter et al., 2016).

Although transformational leadership practices are often described as bottom-up approaches (see Daniëls et al., 2019), this perspective applies only to practices such as staff development, supportive leadership, empowerment, and innovative thinking. Other components, such as providing a vision and leading by example, can be considered aspects that might also include top-down types of leadership activities. Thus, transformational leadership is a combination of strong bottom-up processes and supportive top-down activities (Ruloff & Petko, 2022). There is some evidence that schools with leaders who follow complementary bottom-up and top-down approaches are the most successful in school reforms and integrating technology (Petko, Egger, Cantieni, & Wespi, 2015; Dexter, 2008; Fullan, 1994). For those schools, better technical resources and more intensive use of digital technologies were reported than for schools with other approaches (Petko et al., 2015).

Consistently, several empirical studies have shown a positive relationship between school leaders' transformational leadership behavior and technology integration (Chen, 2013; Ng, 2008; Ottestad, 2013; Seyal, 2015; Vermeulen et al., 2015; Vermeulen et al., 2017; Yamamoto & Yamaguchi, 2019). These studies commonly consider school leaders to be central figures who exhibit transformational leadership practices and influence technology integration. Although shared leadership concepts have long existed in educational research (see Harris, 2013; Spillane, 2005), they are rarely considered in quantitative empirical research on the relationship between transformational leadership and technology integration (the only exception being Chen, 2013, who also surveyed the head of technology and the subject head next to the principal). Notably, transformational and distributed leadership practices are not opposites but can be combined (Daniëls et al., 2019). Therefore, the following section will focus on the findings regarding the impact of school leaders' transformational leadership practices on technology integration. Seyal (2015) provided evidence that the transformational leadership practices of school principals are significantly and positively correlated with different aspects of technology integration at the school level. Moreover, the principal's engagement in transformational leadership activities significantly and positively correlates with digital change at the school level and clear school goals for digital learning and literacy (Ruloff & Petko, 2022). One reason for this could be that transformational leadership, with its components of vision and innovative thinking, is theoretically considered a change-oriented leadership behavior that facilitates and drives change within an organization (Derue, Nahrgang, Wellman, & Humphrey, 2011). In line with this theoretical assumption, a case study showed that principals with such leadership behaviors are more open-minded about information and communication technology (ICT) innovations (Laschou, Kollias, & Karasavvidis, 2018).

However, engagement in transformational leadership by school principals not only has positive effects on technology implementation at the school level but also influences technology integration by individual teachers in the classroom. Various studies have shown that transformational leadership practices carried out by school leaders are positively—directly and indirectly—associated with different indicators of technology integration in class (Chen, 2013; Ng, 2008; Ottestad, 2013; Vermeulen et al., 2015; 2017; Yamamoto & Yamaguchi, 2019).

1.2. Models closing gaps in the research on the relationship between transformational leadership and technology integration

Nevertheless, these studies have also left questions unanswered. For example, Ng's (2008) study only investigated whether teachers believe that certain components of transformational leadership practices carried out by headmasters have a positive impact on their ICT use in the classroom, without statistically analyzing whether transformational leadership practices have a significant effect on any indicator of technology integration. Furthermore, the majority of studies operationalized transformational leadership by measuring whether principals showed transformational leadership behavior in the context of ICT implementation, rather than whether they had transformational leadership behavior in general (see Chen, 2013; Ottestad, 2013; Yamamoto & Yamaguchi, 2019). This might lead to problems of confounding transformational leadership with the dependent variable of technology integration itself.

Although Vermeulen et al. (2015) measured whether school leaders have transformational leadership behavior in general, which avoids the problem of confounding the study's variables, the dependent variable was the intention to use and not the actual use of digital technologies in the classroom. This indicator can only be considered a proxy for actual behavior. Other studies take a different approach by measuring the frequency of technology use, which is a direct indicator of actual behavior (see van Deursen, van Dijk, & Peters, 2012). For example, Ottestad (2013) indicated that transformational leadership is positively associated with hours per week spent on the computer for teaching activities, hours per week spent on the computer for preparation and administrative activities, and a composite index for frequency of technology use items. Yamamoto and Yamaguchi (2019) and Vermeulen et al. (2017) operationalized technology integration by investigating the extent to which teachers use digital technologies in class. Measures that cover the frequency and extent of technology used in class often refer to the quantity of technology integration (Backfisch, Lachner, Stürmer, & Scheiter, 2021). More recently, research has shifted from quantitative aspects of technology integration to aspects such as the affordances of digital technologies to transform learning activities and teaching quality (Backfisch et al., 2021). For example, Fütterer, Scheiter, Cheng, and Stürmer (2022) showed that in mathematics, it is no longer sufficient to focus on the mere frequency of technology use in class to explain students' learning efforts; teaching quality—especially the cognitive activation dimension—also needs to be included. Thus, an operationalization of technology integration that measures how often teachers use or let students use digital technologies to perform cognitively demanding learning activities and is a direct indicator of behavior might be the most preferable measure for the dependent variable. In this case, a good rationale for operationalizing technology integration is the "interactive, constructive, active, passive" (ICAP) model (Antonietti et al., 2023), which has not yet been used to investigate the impact of transformational leadership on technology integration.

Ninković, Florić, and Momčilović (2023) used the ICAP model to show that principals' support regarding ICT in school has no significant direct effect on how often teachers use or let students use digital technologies to foster different learning activities. This is consistent with previous findings that transformational leadership has only indirect positive effects on different indicators of technology integration (see Vermeulen et al., 2015; Vermeulen et al., 2017). Hence, transformational leadership can be considered a distal predictor of technology integration, and there is a need to identify the variables that mediate the relationship between transformational leadership and technology integration. The conceptual model of Petko, Prasse, & Cantieni (2018) provides orientation for the relationship between school leadership and technology integration. It states that school readiness for technology integration, including school leadership, positively influences teacher readiness, which in turn has a positive impact on technology integration. In this model, teacher readiness to integrate technology encompasses teachers' beliefs about digital technologies and their technology-related skills. The authors also mention the "will, skill, tool, pedagogy" model (WSTP model; Christensen & Knezek, 2001; Niederhauser & Lindstrom, 2018) as a suitable framework to operationalize teachers' readiness to integrate technology in class. Consistent with this model, there is empirical evidence that the engagement of the school leader in ICT at their school has a positive influence on the factors of the "will, skill, tool" (WST) model—especially on teachers' attitudes toward teaching with technology—and the factors of the WST model, in turn, have a positive impact on teachers' ICT use in lessons (Petko & Prasse, 2018). Thus, the core enablers, according to the WSTP model (Christensen & Knezek, 2001; Niederhauser & Lindstrom, 2018), could serve as mediators between transformational leadership and technology integration. In line with this, several studies have shown that transformational leadership has significant and positive effects on WSTP-related enablers (Ottestad, 2013; Vermeulen et al., 2015, 2017; Yamamoto & Yamaguchi, 2019).

In summary, there are two major gaps in the literature about transformational leadership and technology integration. The first gap concerns research that has so far focused mostly on the effects of the school principal's transformational leadership on the mere frequency of technology use in class, neglecting other aspects of technology integration. The second gap relates to school leadership as a distal predictor of technology integration (see Ninković et al., 2023; Vermeulen et al., 2015; Vermeulen et al., 2017), and it is necessary to systematically identify the mediators of the relationship between transformational leadership and technology integration. Addressing these two research gaps warrants the combination of two popular models of instructional technology use—the ICAP model and the WSTP model. The ICAP model can serve as an indicator of technology integration to investigate the effects of transformational leadership on how often teachers use or let students use digital technologies to perform cognitively engaging learning activities. This would allow us to examine whether transformational leadership has positive effects on technology integration beyond the mere frequency of technology use. By contrast, the WSTP model provides enablers that could mediate the relationship between transformational leadership and technology integration. This also aligns with previous works suggesting combining different models of instructional technology use to enhance the predictive power of an empirical model and address current research gaps (Tondeur et al., 2021; Guggemos & Seufert, 2021; Niederhauser & Lindstrom, 2018; Sailer, Schultz-Pernice, & Franke, 2021). Thus, the goal of the study was to examine the impact of transformational leadership enacted by school principals on enablers of the WSTP model, which in turn should positively influence technology integration according to the ICAP model. To this end, we asked teachers to rate the leadership behavior of their principals using the global transformational leadership scale developed by Carless et al. (2000). Since we desired to avoid confounding transformational leadership with technology integration, we allowed teachers to assess the leadership behavior of their school principals independently from technology use while maintaining the exact wording of the original scale. As we also investigated the enablers of the WSTP model as mediators between transformational leadership and technology integration, the next two sections deal with the WSTP model and technology integration according to the ICAP model.

1.3. Factors of the will-skill-tool pedagogy model mediating the relationship between transformational leadership and technology integration

The WST model originally included three predictors: (1) will, referring to a positive attitude toward the instructional use of technology; (2) skill, describing either the ability to use technology or the perceived confidence in doing so (self-efficacy); and (3) tool, defined as the availability, accessibility, and quality of devices (Knezek, Christensen, & Fluke, 2003; Niederhauser & Lindstrom, 2018). Many studies have shown that these three enablers predict a high degree of variance in various indicators of technology integration (Agyei & Voogt, 2011; Petko, 2012, Petko, 2012; Farjon, Smits, & Voogt, 2019; Grant, 2019; Knezek & Christensen, 2008, 2016; Knezek et al., 2003; Morales Velazquez, 2007; Pozas & Letzel, 2021; Sasota, Cristobal, Sario, Biyo, & Magadia, 2021). One popular extension of the WST model that adds *pedagogy* as a fourth component (WSTP) leads to an even higher degree of variance explanation. In the WSTP model, it is postulated that skill relates purely to technical aspects, and pedagogy is the skill to teach with digital technologies (Knezek & Christensen, 2015, 2016). According to Knezek and Christensen (2016), pedagogy represents technological pedagogical content knowledge (TPCK) from Mishra and Koehler's (2006) TPACK model. Thus, skill can be operationalized as technological knowledge (TK), the purely technical aspect of this model (see Farjon et al., 2019). The TPACK model of teacher knowledge consists of three components—TK, content knowledge, and pedagogical knowledge—and the overlaps of these three components with TPCK as the interaction between all three core components (Mishra & Koehler, 2006). In contrast to older studies on the WSTP model and technology integration, the operationalization of the skill-related enabler as successfully dealing with basic computer functions seems to be outdated. Advanced digital competencies, such as the skills depicted in the TPACK model, are more relevant for technology integration (Schmitz, Antonietti, Cattaneo, Gonon, & Petko, 2022). In line with this, Guggemos and Seufert (2021) showed that operationalizing factors of the WSTP model along with the TPACK model can lead to successfully predicting technology integration.

Regarding the relationship between leadership and the enablers of the WSTP model, there is some empirical evidence that school principals' support with regard to ICT has positive effects on the enablers of the WSTP model (Petko et al., 2018; 2018). In particular, for transformational leadership, some studies indicate that school leaders' engagement in transformational leadership has positive effects on the enablers of the WSTP model. For example, Vermeulen et al. (2015, 2017) found that transformational leadership practices enacted by principals correspond significantly positively with teachers' positive attitudes toward using digital technologies in class (a will-related enabler of the WSTP model). Vermeulen et al. (2017) showed that transformational leadership has a significant and positive relationship with teachers' professional development with regard to ICT (a skill-related enabler of the WSTP model). Furthermore, some studies indicate that transformational leadership practices carried out by the school leader support the establishment of a good school infrastructure with regard to ICT (a tool-related enabler of the WSTP model; Vermeulen et al., 2015; Yamamoto & Yamaguchi, 2019). Moreover, there is some empirical evidence that principals' engagement in transformational leadership is a positive predictor of teachers' self-efficacy to teach with digital technologies, and their pedagogical attitude with regard to ICT use in class (pedagogy-related enablers of the WSTP model; Ottestad, 2013; Vermeulen et al., 2015; Vermeulen et al., 2017). However, none of the factors of the WSTP model have been studied in parallel when investigating the relationship between transformational leadership and technology integration. So far, no conclusions can be drawn regarding which enabler of the WSTP model of transformational leadership is the strongest predictor.

Further, studies examining the relationship between transformational leadership and technology integration with some of the enablers of the WSTP model as mediators have focused on teachers' intention to use digital technologies in class or the frequency of technology use in class (Vermeulen et al., 2015, 2017). The frequency of technology use in class is a preferable indicator for technology integration over measurements covering beliefs, skills, and familiarity with technology, such as the level of use of technology and the stage of adoption of technology in education, which were very common for assessing technology integration in research focusing on the WSTP model (see, e.g., Agyei & Voogt, 2011; Knezek et al., 2003; Knezek & Christensen, 2016; Sawyerr & Agyei, 2022). As these measures cover aspects that may also include beliefs and skills, they could be confounded by the will- and skill-related enablers of the WST model (Petko, 2012; Petko, 2012). However, using the frequency of technology use in class as an indicator of technology integration also raises some questions. A more recent large-scale assessment study investigating the effects of will-, skill-, and tool-related barriers in various European countries showed that the predictive power of the will-, skill-, and tool-related factors did not exceed 10% for the frequency of technology use by teachers and students in class, which might indicate that these factors no longer play a major role in the frequency of technology use in class (Schmitz et al., 2022). In addition, Schmitz et al. (2022) suggested that future research should examine the effects of the WST model and its extensions on other aspects of technology integration, such as the frequency of teachers using digital technologies or letting students use it to foster students' cognitive engagement rather than the mere frequency of technology use in class. Hence, apart from including the WSTP model to choose factors that mediate the relationship between transformational leadership and technology integration, the ICAP model should be included in recent research to investigate different aspects of technology integration beyond the mere frequency of technology use.

1.4. The ICAP model as a framework to measure technology integration

An interesting approach to assessing technology integration as the frequency of teachers fostering students' cognitively demanding learning activities with digital technologies is offered by the ICAP model (see Antonietti et al., 2023).

This model proposes that students' engagement in learning activities can be differentiated into four modes: interactive, constructive, active, and passive (Chi, 2009; Chi & Wylie, 2014). In this framework, the passive mode of engagement means that students are receptive to instructional activities led by the teacher without overtly doing something themselves. By contrast, the active mode means that students engage in instructional activities provided by the teacher, thus actively reconstructing and applying the knowledge that was previously imparted. The constructive mode of engagement refers to students creating knowledge individually by working on solutions and insights beyond what is provided by the teacher. Lastly, interactive student engagement is considered a dialogue between students, in which the participants collaborate to create new knowledge. In this taxonomy, there is a hierarchy so that a higher mode, such as interactive learning activities, subsumes lower modes, such as passive, active, and constructive learning activities. The ICAP model assumes that from passive to active to constructive to interactive, students' learning and cognitive activation will increase (Chi & Wylie, 2014). The growing body of research on the ICAP model seems to confirm this assumption (Chi et al., 2018; Chi & Wylie, 2014; Morris & Chi, 2020; Wiggins, Eddy, Grunspan, & Crowe, 2017).

More recently, the ICAP model has been applied to teaching and learning with digital technology (see, e.g., Sailer, Schultz-Pernice, & Fischer, 2021; Sailer, Schultz-Pernice, & Franke, 2021). Stegmann's (2020) meta-analysis showed that instructional activities using digital technologies can be categorized according to the ICAP model. This meta-analysis found some initial evidence that student learning with digital technologies yields more promising results when higher-order learning activities are addressed. In using the ICAP model in the context of technology integration, similarities to the substitution, augmentation, modification, and redefinition (SAMR) model by Puentedura (2012) become salient. The SAMR model has a hierarchical structure that focuses on learning tasks: The lowest level of substitution indicates that digital technologies simply replace analog teaching methods, whereas augmentation goes further, in that the digital tool not only replaces the analog tool but also enhances it. With regard to redefinition, the tool allows for a fundamental redesign of the learning task. At the highest level of redefinition, digital technology enables the creation of entirely new learning tasks. The clear difference between the SAMR model and the ICAP model lies in the underlying basis of their structures: whereas in the ICAP model, the hierarchical structure is based on how cognitively activating the learning activities are designed, the SAMR model is about the innovation potential of digital technologies to redesign a learning task. The SAMR model has often been criticized for its technocentric focus, and studies have shown that for schools with effective technology integration, pedagogical instead of technical approaches are crucial (Kozma, 2003; Pelgrum & Anderson, 1999; Venezky & Davis, 2002). Thus, the ICAP model, which covers pedagogical innovations and cognitive activation, might be preferable in the context of technology integration.

This can be supplemented by recent findings showing that using digital technology to promote passive, active, and interactive learning activities leads to students self-reporting a higher motivation than when these learning activities are promoted without digital technology (Wekerle, Daumiller, & Kollar, 2022). Therefore, measuring how often teachers use digital technology to promote passive, active, constructive, and interactive learning activities among students seems particularly appropriate for capturing another aspect of technology integration apart from the mere frequency of technology use. This operationalization of technology integration is consistent with Backfisch et al.'s (2021) and Fütterer et al.'s (2022) views that other aspects of technology integration apart from the mere frequency of technology and application use refer to teachers' quality of teaching with digital technologies, especially the dimension of cognitive activation, which refers to task-specific instructional strategies that foster students' cognitive engagement in class.

1.5. Research hypotheses

This study aims to address the following research question: How is school principals' alignment with transformational leadership related to teachers' core enablers and technology integration?

Based on earlier findings, the present study proposes the following hypotheses.

1. Higher levels of principals' transformational leadership are positively related to higher levels of central enablers depicted in the WSTP model (will, skill, tool availability, and pedagogy of teachers).
2. Higher levels of principals' transformational leadership are positively related to higher levels of technology integration (operationalized according to the ICAP model).

3. Enablers (will, skill, tool availability, and pedagogy of teachers) of the WSTP model are significant mediators for the relationship between transformational leadership and higher levels of technology integration (operationalized according to the ICAP model).

The third hypothesis is illustrated by the conceptual model in Fig. 1. Here, we expect that transformational leadership, in alignment with previous findings (see Ottestad, 2013; Vermeulen et al., 2015; 2017; Yamamoto & Yamaguchi, 2019), has a positive effect on will-, skill-, tool-, and pedagogy-related enablers of the WSTP model and that, in turn, all factors of the WSTP model positively influence technology integration operationalized according to the ICAP model.

2. Material and methods

2.1. Participants and procedures

The study is based on a voluntary national survey of upper secondary education teachers in Switzerland. The first survey wave for the canton of Zurich was collected from September 20 to November 8, 2021, followed by the second survey wave for all other cantons in Switzerland from May 1 to August 1, 2022. In this study, around 37,370 teachers who teach in the second and third years of 526 upper secondary schools were invited to participate in an online survey. In total, 2248 teachers (6.0% of the whole sample) from 113 schools (21.5% of the whole sample of schools) completed our online questionnaire. There was a school represented by only one teacher; this case was excluded from the analyses, resulting in a final analytical sample of 2247 teachers from 112 schools. A full population was not achieved, and the data were slightly skewed: The national sample consists of around 31% general education schools, 60% vocational education schools, and 9% of schools that combine vocational and general education, whereas in our sample, 41.6% of the schools can be categorized as general education schools, 46.9% as vocational education schools, and 11.5% as schools combining vocational and general education. With regard to the language region in the national population, 65% of the schools are located in the German-speaking region of Switzerland, 28% in the French-speaking area, and 7% in the Italian-speaking region. However, in our sample, 75.2% of the schools were in the German-speaking region of Switzerland, 10.6% were francophone schools, and 14.2% were located in the Italian-speaking area. Therefore, sampling weights were calculated and applied to the data for the descriptive parts of the analysis using the following formula to account for the uneven distribution of responses in schools, school types, and language regions:

Weight = a(N of teachers who taught in the school/N of respondents in the school)*b(N of teachers in a language region/N of respondents in a language region)*c(N of teachers teaching in a school type/N of respondents in a school type) *(Mean (a*b*c))

In our sample, 50.5% of teachers were male, 47.3% were female, and 2.2% chose the response option "other" for their gender. About 41.8% of teachers indicated that they taught in a general education track, 40.7% indicated that they taught in a vocational education track, and 17.5% of teachers were employed in schools that combine vocational education and general education. Regarding the language region, 79.2% of the teachers in our sample were located in the German-speaking part of Switzerland, 11.3% of teachers taught in the Italian-speaking region of Switzerland, and 9.5% of teachers taught in the francophone region.

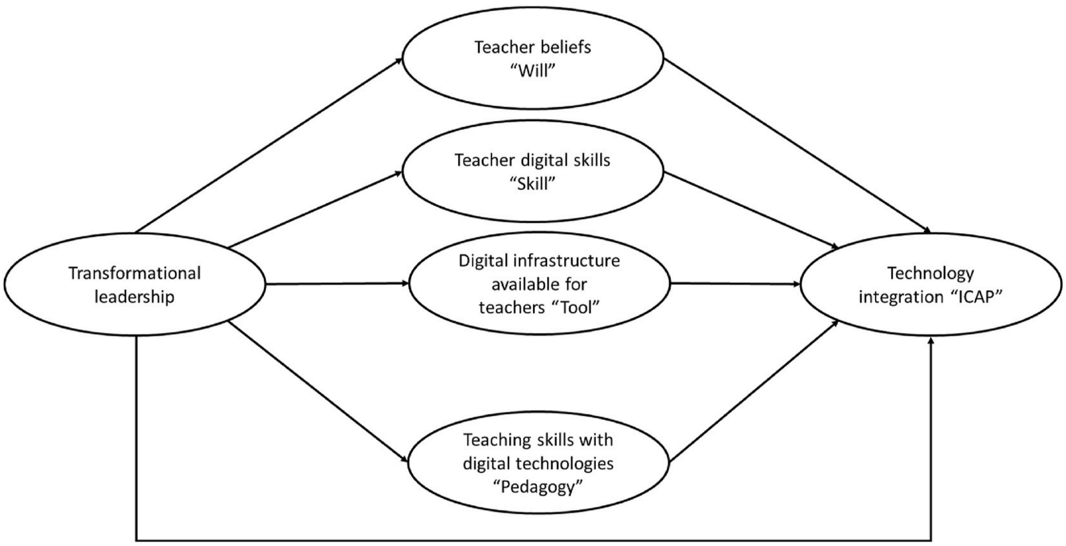


Fig. 1. Conceptual model.

2.2. Measures

2.2.1. Transformational leadership

Transformational leadership was measured using seven items from the Global Transformational Leadership Scale developed by Carless et al. (2000). This instrument has been validated in many international studies that have confirmed the unidimensionality and reliability of the scale (e.g., see Ghadi, Fernando, & Caputi, 2013; Gillet, Fouquereau, Bonnaud-Antignac, Mokounkolo, & Colombat, 2013; Munir, Nielsen, & Carneiro, 2010; Scheel, Otto, Vahle-Hinz, Holstad, & Rigotti, 2019; van Beveren, Dimas, Lourenço, & Rebelo, 2017). Teachers had to assess how often their school leaders engaged in the following seven forms of leadership behavior: vision, staff development, supportive leadership, empowerment, innovative thinking, leading by example, and charismatic leadership. One item was assigned to each of the leadership areas (see Table 1). The response options ranged from 1 (*never*) to 5 (*always*). A confirmatory factor analysis (CFA) indicated a good fit for the assumption that all items load onto one factor (Chi^2 (11) = 159; $p < .001$; TLI = 0.981; CFI = 0.990; RMSEA = 0.078; SRMR = 0.013). For the TLI and CFI, values higher than 0.95 were considered a good fit, as were values of RSMEA and SRMR lower than 0.08 (Brown, 2015; Hu & Bentler, 1999). According to the modification indices, three residual correlations between the items were added to improve the model fit. The reliability of the scale was estimated using Cronbach's α and McDonald's ω. Both reliability indices were 0.95.

2.2.2. Enablers of technology integration

The will component of the WST model was operationalized with four items according to Petko (2012). Teachers were asked to indicate how much they agreed with statements about the positive effects of using digital technologies in the classroom (e.g., "Through the use of digital technologies, I can improve the quality of my teaching"). The answer options ranged from 1 *(totally disagree)* to 5 *(totally agree)*. Reliability for will was 0.90 each for Cronbach's α and McDonald's ω.

Following the suggestions of previous studies (see Schmitz et al., 2022; Farjon et al., 2019; Guggemos & Seufert, 2021), to avoid measuring skill as handling basic computer tasks and instead using TPACK as a rationale to operationalize skill, the skill component was measured with three items related to TK, following Schmid, Brianza and Petko (2020) (e.g., "I know many different digital technologies"). The answer options were the same as for the will component. For skill, the reliability was.86 for Cronbach's α and.87 for McDonald's ω.

The tool component was assessed with three items, following Petko et al. (2018). Teachers do not only teach in one particular classroom; thus, they were asked to rate the quality of the school's computer infrastructure in general, instead of assessing the quality of the technical equipment of one classroom (e.g., "How would you rate your school's overall computer infrastructure?") with regard to hardware, internet connectivity, and technical support. The answer options ranged from 1 (*very bad*) to 5 (*very good*). The reliability of the tool was 0.76 for Cronbach's α and 0.77 for McDonald's ω.

According to Christensen and Knezek (2001), pedagogy can be operationalized by the TPCK component of the TPACK model. Thus, the pedagogy component was measured with three items related to TPCK, following Schmid et al. (2020) (e.g., "I can use strategies that combine subject content, digital technology, and teaching methods in a meaningful way"). The answer options were the same as for the will and skill components. For pedagogy, the reliability was 0.87 for Cronbach's α and McDonald's ω.

A CFA confirmed the categorization according to the WSTP model (Chi^2 (59) = 408; $p < .001$; TLI = 0.970; CFI = 0.977; RMSEA = 0.051; SRMR = 0.033). No residual correlations were needed.

2.2.3. Technology integration

For technology integration, we used the ICAP technology scale developed by Antonietti et al. (2023). For the passive dimension, teachers were asked to indicate how often they used digital technologies to promote students' passive learning activities. (e.g., "To inform about learning objectives and content"). For the other three dimensions (active, constructive, and interactive), teachers were asked to indicate how often their students used digital technologies for learning activities (active: e.g., "so that they actively repeat and practice the knowledge imparted"; constructive: e.g., "so that they can acquire new knowledge individually"; and interactive: e.g., "so that they develop new knowledge together with others"). Each of the four dimensions (passive, active, constructive, and interactive) consisted of three items, which are presented in Table 2. The answer options were rated on a Likert scale from 1 *(Almost never)* to 5 *(Almost every lesson)*.

Antonietti et al. (2023) showed that the fit indices of the second-order CFA with an overarching factor "technology integration" for the four dimensions (passive, active, constructive, and interactive) can be rated as good and that a first-order CFA does not fit the data

Table 1
Overview of the global transformational leadership scale.

Leadership behavior	Item
Vision	The school leader communicates a clear and positive vision of the future.
Staff development	The school leader treats staff as individuals, supports and encourages their development.
Supportive leadership	The school leader gives encouragement and recognition to staff.
Empowerment	The school leader fosters trust, involvement, and cooperation among team members.
Innovative thinking	The school leader encourages thinking about problems in new ways and questions assumptions.
Leading by example	The school leader is clear about his/her values and practices what he/she preaches.
Charisma	The school leader instills pride and respect in others and inspires me by being highly competent.

Note. The answer format is a five-point Likert scale: 1 Never – 5 Always.

Table 2
Overview of the ICAP technology scale.

Dimension	Question	Item
passive	For which teaching and learning activities do you use digital technologies?	To inform about learning objectives and content.
		To demonstrate learning content vividly.
		To explain learning content in a comprehensible way.
Active	For which learning activities do your students use digital media in your lessons?	So that they write down and record the knowledge imparted.
		So that they actively repeat and practice the knowledge imparted.
		So that they can solve simple tasks with the knowledge imparted.
Constructive		So that they can acquire new knowledge individually.
		So that they can develop individual solutions for complex problems.
		So that they can become individually creative and produce something new.
Interactive		So that they develop new knowledge together with others.
		So that they can discuss different points of view with others.
		So that they work in working groups on complex problems.

Note. The answer format is a five-point Likert scale: 1 Almost never – 5 Almost every lesson.

significantly better, indicating that an overarching factor for the four dimensions is preferable. Further, for this sample, the second-order CFA shows a good fit (Chi^2 (48) = 609; $p < .001$; TLI = 0.966; CFI = 0.975; RMSEA = 0.072; SRMR = 0.031) with two modifications. Conceptually, a higher mean score for the overarching dimension "technology integration" indicates that teachers use technology to promote more cognitively demanding learning activities for students, since a higher mode of ICAP subsumes lower modes (Chi & Wylie, 2014). Similarly, a study by Antonietti et al. (2023) showed that the different ICAP dimensions build hierarchically on each other. Thus, a higher mean value of the overarching factor "technology integration" should indicate that teachers not only use digital technologies frequently to promote passive and active learning activities but that they also let students use digital technologies very regularly to engage in more cognitively demanding learning activities (constructive and interactive). The reliability of the 12-item technology integration scale was 0.93 for Cronbach's α and 0.94 for McDonald's ω.

The items of the scales transformational leadership, will, skill, tool, pedagogy, and the ICAP technology scale had a skewness of <2 and a kurtosis of <7 indicating that their use was not problematic for structural equation modeling with maximum likelihood estimation (see Curran, West, & Finch, 1996).

2.3. Statistical analysis

2.3.1. Descriptive statistics

Means and standard deviations were calculated for the scores of all constructs with the use of sampling weights to account for the uneven distribution of participant numbers per school, language region, and school type. The weighting was carried out to obtain an approximately equal distribution as in a full survey (Kish & Frankel, 1974). However, unweighted data were used for all other inferential statistical procedures that follow, as weighted data could potentially distort the results (Gelman, 2007; Winship & Radbill, 1994).

2.3.2. Inferential statistics

To test the first two hypotheses, multilevel correlations were performed with the package seolmatrix of Jamovi (1.6.10), as the teachers were nested in schools. The multilevel correlation coefficients were interpreted according to Cohen (1992): correlations with $r > 0.10$ were considered weak, correlations with $r > 0.30$ were classified as moderate, and correlations with $r \geq 50$ were identified as strong.

To test the third hypothesis, a structural equation model (SEM) was tested following the conceptual model depicted in Fig. 1. As a latent multilevel SEM with one mediator requires 100 clusters (McNeish, 2017; Zigler & Ye, 2019), and our sample of teachers was nested only in 112 schools (clusters) and four mediators should be examined, we had to follow a different approach. Given that multilevel linear modeling (MLM) mediation with Kenward Roger correction is only a simplification of the complex model, we performed a latent one-level SEM with cluster robust standard errors to consider the multilevel structure of the data (see Oberski, 2014; Stapleton, McNeish, & Yang, 2016). Due to the small sample, it was also not possible to present the effects of transformational leadership and the four enablers on the passive, active, constructive, and interactive dimensions of ICAP in one model. Therefore, the mediation model was conducted following the conceptual model depicted in Fig. 1 with the overarching factor "technology integration," which includes the four dimensions of the ICAP model as a dependent variable. For the analyses, the software package lavaan (0.6–7) in R (4.0.2.) was used.

3. Results

3.1. Descriptive statistics

The descriptive statistics showed that on average, teachers' ratings were rather positive on all accounts, with a substantial variation that needed to be explained in subsequent analyses.

Table 3 illustrates the descriptive statistics for all constructs.

3.2. Multilevel correlation analysis

Table 4 shows the results of the multilevel correlation analysis that confirmed our first hypothesis: Transformational leadership was positively and significantly related to all enablers. The correlations of transformational leadership with will, skill, and pedagogy scores were small, and the correlation with tool scores was moderate. Regarding the second hypothesis, Table 4 presents a significant, positive, and small correlation between transformational leadership and technology integration. Further, technology integration was positively and significantly correlated with will, skill, tool, and pedagogy scores. For will, skill, and pedagogy scores, the correlations were categorized as moderate. Nevertheless, the correlation with tool scores was smaller than $r = .10$ and was considered negligible. Even after Bonferroni correction, all mentioned correlations remained significant.

3.3. Structural equation modeling

To test the effects of transformational leadership, we performed item parceling to enable mediation with cluster robust standard errors in the mediation model. Typically, three to four items per latent variable are optimal for achieving a good model fit. Therefore, mean values consisting of items similar in content were formed. After the first item ("The school leader communicates a clear and positive vision of the future"), the second and third items of the scale formed a parcel, because both involve encouraging and appreciating the employees ("The school leader treats staff as individuals, supports and encourages their development" and "The school leader gives encouragement and recognition to staff"). Similarly, a mean value was formed from the fourth and fifth items, since these are about promoting the competencies and commitment of the employees ("The school leader fosters trust, involvement, and cooperation among team members" and "The school leader encourages thinking about problems in new ways and questions assumptions"). Lastly, a parcel was also formed from the sixth and seventh items, which refer to the leader setting a good example ("The school leader is clear about his/her values and practices what he/she preaches" and "The school leader instills pride and respect in others and inspires me by being highly competent"). This parceling resulted in a good model fit for the mediation model (Chi^2 (357) = 1742.557; $p < .001$; TLI = 0.960; CFI = 0.965; RMSEA = 0.045; SRMR = 0.043). Only one modification was needed (residual correlation of the interactive and constructive dimensions of the ICAP scale). All factor loadings of the constructs (transformational leadership, will, skill, tool, pedagogy, and technology integration) were ≥0.60 and can be categorized as strong, according to Garson (2009). Thus, all items loaded well on their intended factor. The results of the SEM model are depicted in Fig. 2. The R^2 was 0.28, indicating that 28% of the variance in technology integration could be explained by the other variables of the model.

The SEM revealed that transformational leadership had no significant direct impact on technology integration, but it significantly and positively predicted all enablers. Will, skill, and pedagogy scores, but not tool scores, showed a significant and positive impact on technology integration. Comparing the standardized path coefficients, transformational leadership seems to have the strongest effect on the tool-related factor of the WSTP model. Regarding the standardized betas of the enablers, will and pedagogy scores seem to have the highest impact on technology integration.

Table 5 shows that the indirect effects of will, skill, and pedagogy scores were significant. The indirect effect of tool scores was not significant. However, the total effect was also significant. In summary, the third hypothesis was only partially confirmed, as will, skill, and pedagogy scores, but not tool scores, significantly mediated the relationship between transformational leadership and technology integration.

Table 3
Descriptive statistics.

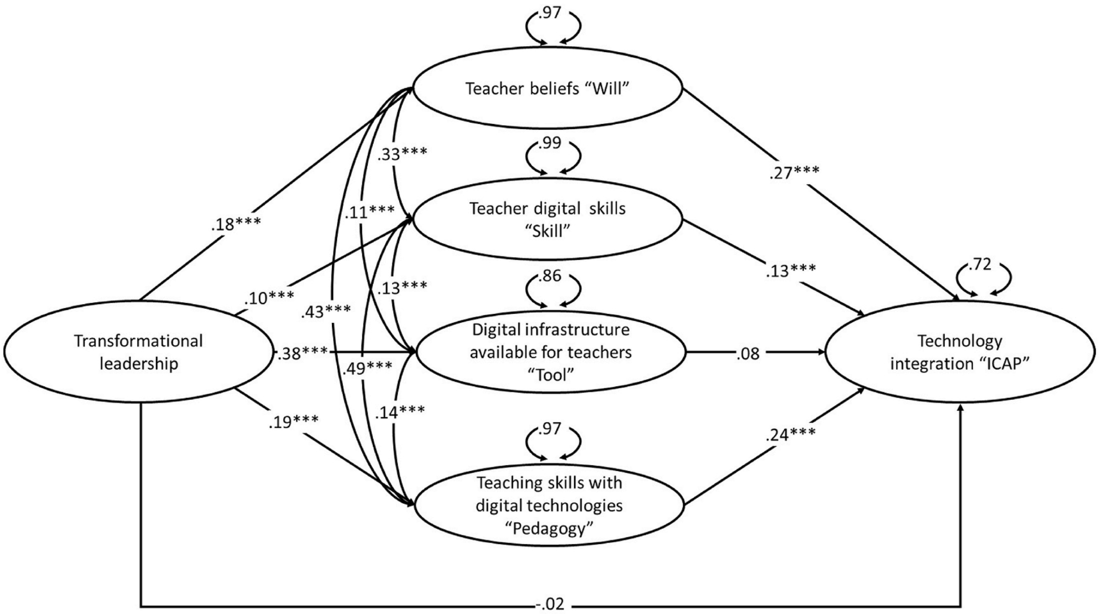
	Mean	SD
Transformational leadership	3.69	0.95
Will	3.38	0.95
Skill	3.21	1.05
Tool	3.70	0.95
Pedagogy	3.91	0.85
Technology integration	3.25	0.97

Note. Means and standard deviations (SD) are weighted. All measures are on 5-point scales.

Table 4
Results of the multilevel correlation analysis.

Variable1	Variable2	r	p	Lower CI	Upper CI
leadership	Will	.18	<.001	.14	.22
leadership	Skill	.11	<.001	.07	.15
leadership	Tool	.36	<.001	.32	.39
leadership	Pedagogy	.17	<.001	.13	.21
leadership	Technology integration	.11	<.001	.07	.15
Will	Skill	.31	<.001	.28	.35
Will	Tool	.15	<.001	.10	.19
Will	Pedagogy	.41	<.001	.38	.45
Will	Technology integration	.42	<.001	.38	.45
Skill	Tool	.11	<.001	.07	.15
Skill	Pedagogy	.43	<.001	.40	.46
Skill	Technology integration	.30	<.001	.27	.34
Tool	Pedagogy	.15	<.001	.11	.19
Tool	Technology integration	.08	<.001	.04	.12
Pedagogy	Technology integration	.37	<.001	.34	.41

Note. N = 2247, df = 2245, CI = confidence interval.new.



Note. *** p <.001, ** p <.01, * p <.05. All standardized path coefficients and covariances between latent variables and the variances explained by the endogenous variables are displayed. The measurement models are not displayed.

Fig. 2. Structural equation model
Note. ***p < .001, **p < .01, *p < .05. All standardized path coefficients and covariances between latent variables and the variances explained by the endogenous variables are displayed. The measurement models are not displayed.

Table 5
Standardized indirect and total effects.

	Estimate	SE	p	CI lower	CI upper
Indirect effect will	.05	.01	.000	.03	.07
Indirect effect skill	.01	.01	.007	.00	.02
Indirect effect tool	.03	.02	.060	−.00	.06
Indirect effect pedagogy	.05	.01	.000	.03	.06
Total	.12	.03	.000	.06	.18

Note. Standard errors (SE) are cluster robust, CI = confidence interval.

4. Discussion

4.1. Summary of the results

Our results confirm the first hypothesis that transformational leadership is significantly and positively correlated with the will, skill, tool, and pedagogy factors perceived by teachers. This aligns with previous studies indicating that principals' engagement in transformational leadership practices corresponds positively with the enablers of the WSTP model (Ottestad, 2013; Vermeulen et al., 2015, 2017; Yamamoto & Yamaguchi, 2019). The second hypothesis was also confirmed, as the multilevel correlation analysis revealed a significant and positive correlation with technology integration, which can be considered small. In contrast to previous studies (see Ottestad, 2013; Vermeulen et al., 2017; Yamamoto & Yamaguchi, 2019), this analysis provides the first empirical evidence that transformational leadership is not only significantly positively related to the mere frequency of technology use but also is significantly positively correlated with technology integration operationalized according to the ICAP model. Consequently, this study extends the current literature by showing that transformational leadership practices might not only be helpful in promoting a more frequent use of digital technologies in class but that transformational school leaders seem to also support teachers in fostering different learning activities with digital technologies, which place different demands on students' cognitive engagement.

Regarding the mediation model, we found that transformational leadership had no significant direct impact on technology integration. It seems that transformational leadership—which, in contrast to other studies (see Chen, 2013; Ottestad, 2013; Yamamoto & Yamaguchi, 2019), we measured globally and not specifically related to ICT implementation—has a rather indirect effect on indicators of technology integration. These findings confirm previous studies revealing that principals' leadership practices have distal effects on different indicators of technology integration, stressing the need to identify the variables mediating the relationship between transformational leadership and technology integration (see Ninković et al., 2023; Vermeulen et al., 2015; 2017). To address this need, we examined whether factors of the WSTP model, particularly teachers' positive beliefs toward digital technologies in class (will), their technical skills (skill), the quality of the school's digital infrastructure (tool), and their teaching skills with digital technologies (pedagogy), mediate the relationship between transformational leadership and technology integration operationalized according to the ICAP model. We found that the third hypothesis was only partially supported by the results. Indeed, will, skill, and pedagogy scores, but not tool scores, significantly mediated the relationship between transformational leadership and technology integration, as operationalized according to the ICAP model. This again confirms the trend in highly developed countries (e.g., Switzerland) that tool is now only a marginal or non-significant predictor of technology integration (see Petko & Prasse, 2018).

Morales Velazquez (2007) postulated that at the lowest stage of technology adoption, tool is the most important predictor for technology integration, while at higher stages, will and skills are more important predictors. Schmitz et al. (2022) offered empirical evidence that this assumption also applies to the European context: In technologically developed countries, teachers' beliefs had a major influence on technology integration, whereas in less technologically developed countries, tool-related factors played an important role. In a technologically developed country such as Switzerland, personal enablers, such as teachers' positive beliefs about technology (will), good technical skills (skill), and skills for using technology in class (pedagogy), have a greater influence on technology integration than the schools' infrastructure (tool), especially since the global pandemic has led to further improvements in technical equipment in Swiss schools (see Huber, 2021; Huber & Helm, 2020).

Further, the integration of the mediating variables based on the WSTP model in our SEM analysis allowed us to provide the first empirical evidence on which factors of the WSTP model transformational leadership has the strongest impact. SEM analysis revealed that transformational leadership was the strongest predictor for the tool-related enabler, indicating that the transformational leadership behavior of the principal is helpful in establishing good quality for the school's technical equipment. Most previous studies investigated the effects of factors derived from the WSTP model on the frequency of technology use in class or teachers' beliefs, skills, and familiarity with digital technologies (Agyei & Voogt, 2011; Petko, 2012, Petko, 2012, Schmitz et al., 2022; Knezek et al., 2003; Sasota et al., 2021; Sawyerr & Agyei, 2022). This study goes beyond the current body of literature by showing that the enablers of the WSTP model also have a significant and positive effect on technology integration, as measured based on the ICAP model.

4.2. Limitations and directions for future research

The first limitation of this study relates to the self-reported data of teachers, as teachers tend to overestimate their own competencies in teaching with technologies and their level of technology integration in class (Kopcha & Sullivan, 2007). Students could have been surveyed on the dependent variable of technology integration to avoid mono-source bias. However, this would have involved much more effort in data collection, as it would have been necessary to ensure that students were accurately assessing the teacher who, for our study, had previously self-assessed their beliefs, technical skills, the quality of the infrastructure, and their skills to teach with digital technology. Another option to avoid the mono-method bias would have been to ask principals to rate their own leadership practices, which would also offer the advantage of excluding the problem of different perceptions of teachers about the same school leader. However, to integrate the principals' assessments of their transformational leadership practices into the analysis, a complex multilevel SEM should have been conducted instead of only an SEM with cluster-robust standard errors. However, in our sample, there are not enough clusters for complex multilevel SEM analysis analyses (see McNeish, 2017; Zigler & Ye, 2019). Therefore, future research should conduct more complex multilevel SEM analyses with enablers as mediators if the sample size requirements are met. Moreover, the operationalization of the tool-related enabler can be criticized, as the teachers were only asked to rate the general quality of the schools' infrastructure, and therefore no conclusions can be drawn on the quality of the technical equipment in a specific classroom. However, as teachers teach in several classrooms, it would not have made sense to let them rate the quality of the infrastructure of one specific classroom. As very complex SEM mediation analyses require very large samples (see McNeish, 2017; Stapleton et al., 2016; Zigler & Ye, 2019), we were unable to examine the differential effects on single dimensions of ICAP in one mediation model, given the limited sample size of our study. Hence, future studies should focus on the differential effects of enablers on passive, active, constructive, and interactive technology integration. However, the study by Antonietti et al. (2023) showed that the four dimensions are subordinated to an overarching factor "technology integration" and also conceptually a higher mode of ICAP subsumes lower modes (Chi & Wylie, 2014) so that even without looking at the individual dimensions, conclusions can already be drawn in this study about which factors contribute to a higher level of technology integration.

Furthermore, the controversial technique of item parceling was used in this study to enable the construction of a model with cluster robust standard errors (see Little, Rhemtulla, Gibson, & Schoemann, 2013; Marsh, Lüdtke, Nagengast, Morin, & Davier, 2013). Nevertheless, the study can be credited with the fact that the unidimensionality of the transformational leadership scale has already been proven in many studies (for example, see Ghadi et al., 2013; Gillet et al., 2013; Munir et al., 2010; Scheel et al., 2019; van Beveren et al., 2017). Moreover, the parcels were formed in a theory-driven manner, which is preferable to parcels formed from purely statistical considerations (Little et al., 2013; Marsh et al., 2013). Another limitation relates to our cross-sectional data, since mediation might consist of processes that unfold over time (Maxwell & Cole, 2007). Thus, it would also be interesting to perform a mediation analysis with longitudinal data, such as Vermeulen et al. (2017).

For reasons of instrument acceptability by participating teachers and time efficiency, we chose to measure transformational leadership using Carless et al.'s (2000) short scale consisting of 7 items. However, other more recent measurement instruments stress leadership practices instead of leader characteristics even more and depict transformational leadership in much greater detail. Using detailed measurements with more items and different sub-dimensions of transformational leadership, previous studies have shown the relative effects of sub-dimensions of transformational leadership on enablers and indicators of technology integration in greater detail (Chen, 2013; Vermeulen et al., 2015, 2017; Yamamoto & Yamaguchi, 2019). Future studies should investigate the relationship between the sub-dimensions of transformational leadership, enablers, and technology integration. Further, we did not compare transformational leadership with other leadership practices, such as instructional or distributed leadership. Future research could examine the effects of several leadership practices in parallel, as demonstrated by Chen (2013) and Ottestad (2013). We did not conduct an experimental design with transformational leadership training for part of the school principals, and with a survey study, no clear statements about the causality of the effects could be made. Finally, the sample consisted only of upper secondary school teachers; thus, further research is needed to determine whether the results are transferable to other levels of the school system or to other countries.

4.3. Conclusions

Previous studies have shown that transformational leadership behaviors carried out by principals positively predict the frequency and extent of teachers' use of digital technologies and their intention to use them in class (Ottestad, 2013; Vermeulen et al., 2015, 2017; Yamamoto & Yamaguchi, 2019). In our study, we showed that headmasters who regularly engage in transformational leadership practices, as perceived by teachers, effectively support teachers in fostering students' cognitively demanding learning activities with digital technologies more than principals who score lower on the transformational leadership scale perceived by teachers. In contrast to previous studies (see Chen, 2013; Ottestad, 2013; Yamamoto & Yamaguchi, 2019), we did not ask the teachers to rate the transformational leadership practices of their school principal with specific regard to technology use. Nevertheless, we found that transformational leadership measured globally also promotes enablers, which in turn empower teachers to use technology in a more demanding way. Moreover, several studies have already indicated that transformational leadership has a significant and positive impact on all enablers of the WSTP model (Ottestad, 2013; Vermeulen et al., 2015, 2017; Yamamoto & Yamaguchi, 2019), but in those studies, the enablers were not investigated in parallel, and it was not possible to identify which enablers were most strongly predicted by transformational leadership. Our study provides empirical evidence that transformational leadership has the strongest positive relationship with the quality of the infrastructure, which means that the transformational leadership practices of the principal are particularly conducive to bringing the school up to the latest technical standards. However, in line with previous findings (Schmitz et al., 2022), this study indicates that in highly technologically developed countries, the quality of the infrastructure is not the most essential factor in technology integration. In this regard, teachers' positive attitudes toward digital technologies, their digital skills, and their skills in teaching with digital technologies seem to play a more important role, on which transformational leadership also has positive effects. Thus, teachers are vital to technology integration in class, and transformational leadership might be a helpful approach for school leaders to support them in this regard.

Credit author statement

Maria-Luisa Schmitz: Data Curation, Investigation, Formal analysis, Conceptualization, Writing – original draft, Writing – review and editing, Chiara Antonietti: Data Curation, Investigation, Writing – review and editing, Tessa Consoli: Data Curation, Investigation, Writing – review and editing, Alberto Cattaneo: Project administration, Funding acquisition, Supervision, Writing – review and editing, Philipp Gonon: Project administration, Funding acquisition, Supervision, Writing – review and editing, Dominik Petko: Project administration, Funding acquisition, Supervision, Conceptualization, Writing – review and editing.

Data availability

The data of this research will be publicly available in 2024.

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There are no conflicts of interest. Our study complies with the ethical standards of the Swiss Academy of Social Sciences and Humanities.

References

Agyei, D. D., & Voogt, J. M. (2011). Exploring the potential of the will, skill, tool model in Ghana: Predicting prospective and practicing teachers' use of technology. *Computers & Education, 56*(1), 91–100. https://doi.org/10.1016/j.compedu.2010.08.017

Anderson, M. (2017). Transformational leadership in education: A review of existing literature. *International Social Science Review, 93*(1), 1–13.

Antonietti, C., Schmitz, M. L., Consoli, T., Cattaneo, A., Gonon, P., & Petko, D. (2023). Development and validation of the ICAP Technology Scale to measure how teachers integrate technology into learning activities. *Computers & Education, 192*, 104648. https://doi.org/10.1016/j.compedu.2022.104648.

Backfisch, I., Lachner, A., Stürmer, K., & Scheiter, K. (2021). Variability of teachers' technology integration in the classroom: A matter of utility. *Computers & Education, 166*, Article 104159. https://doi.org/10.1016/j.compedu.2021.104159

Bass, B. M. (1990). From transactional to transformational leadership: Learning to share the vision. *Organizational Dynamics, 18*(3), 19–31.

Tondeur, J., Petko, D., Christensen, R., Drossel, K., Starkey, L., Knezek, G., & Schmidt-Crawford, D. A. (2021). Quality criteria for conceptual technology integration models in education: Bridging research and practice. *Educational Technology Research and Development, 1-22*. https://doi.org/10.1007/s11423-020-09911-0.

van Beveren, P., Dimas, I. D., Lourenço, P. R., & Rebelo, T. (2017). Psychometric properties of the Portuguese version of the global transformational leadership (GTL) scale. *Revista de Psicologia Del Trabajo Y De Las Organizaciones, 33*(2), 109–114. https://doi.org/10.1016/j.rpto.2017.02.004

Brown, T. A. (2015). *Confirmatory factor analysis for applied research*. Guilford Publications.

Carless, S. A., Wearing, A. J., & Mann, L. (2000). A short measure of transformational leadership. *Journal of Business and Psychology, 14*(3), 389–405.

Chen, W. (2013). School leadership in ICT implementation: Perspectives from Singapore. *The Asia-Pacific Education Researcher, 22*(3), 301–311. https://doi.org/10.1007/s40299-012-0055-8

Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*(1), 73–105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

Chi, M. T. H., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., et al. (2018). Translating the ICAP theory of cognitive engagement into practice. *Cognitive Science, 42*(6), 1777–1832. https://doi.org/10.1007/s11423-022-10096-x

Chiu, T. K. F. (2022). School learning support for teacher technology integration from a self-determination theory perspective. *Educational Technology Research & Development, 70*(3), 931–949. https://doi.org/10.1007/s11423-022-10096-x

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Christensen, R., & Knezek, G. (2001). Instruments for assessing the impact of technology in education. *Computers in the Schools, 18*(2–3), 5–25. https://doi.org/10.1300/J025v18n02_02

Cohen, J. (1992). Quantitative methods in psychology: A power primer. *Psychological Bulletin, 112*(1), 1155–1159.

Curran, P. J., West, S. G., & Finch, J. F. (1996). The robustness of test statistics to nonnormality and specification error in confirmatory factor analysis. *Psychological Methods, 1*(1), 16. https://doi.org/10.1037/1082-989X.1.1.16

Daniëls, E., Hondeghem, A., & Dochy, F. (2019). A review on leadership and leadership development in educational settings. *Educational Research Review, 27*, 110–125. https://doi.org/10.1016/j.edurev.2019.02.003

Derue, D. S., Nahrgang, J. D., Wellman, N. E. D., & Humphrey, S. E. (2011). Trait and behavioral theories of leadership: An integration and meta-analytic test of their relative validity. *Personnel Psychology, 64*(1), 7–52. https://doi.org/10.1111/j.1744-6570.2010.01201.x

van Deursen, A. J., van Dijk, J. A., & Peters, O. (2012). Proposing a survey instrument for measuring operational, formal, information, and strategic internet skills. *International Journal of Human-Computer Interaction, 28*(12), 827–837. https://doi.org/10.1080/10447318.2012.670086

Dexter, S. (2008). Leadership for IT in schools. In J. Voogt, & G. Knezek (Eds.), *International handbook of information technology in primary and secondary education* (pp. 543–554). Springer. https://doi.org/10.1007/978-0-387-73315-9_32.

Dexter, S. (2018). The role of leadership for information technology in education: Systems of practices. In G. J Voogt, R. Knezek, & K. W. L. Christensen (Eds.), *Second handbook of information technology in primary and secondary education* (pp. 483–498). Springer international handbooks of education. https://doi.org/10.1007/978-3-319-71054-9_32. Springer.

Dexter, S., & Richardson, J. W. (2020). What does technology integration research tell us about the leadership of technology? *Journal of Research on Technology in Education, 52*(1), 17–36. https://doi.org/10.1080/15391523.2019.1668316

Dexter, S., Richardson, J. W., & Nash, J. B. (2016). A review of the empirical research and implications for leadership preparation. In M. D. Young, & G. M. Crow (Eds.), *Handbook of research on the education of school leaders* (pp. 202–228).

Eickelmann, B. (2011). Supportive and hindering factors to a sustainable implementation of ICT in schools. *Journal for Educational Research Online, 3*(1), 75–103. https://doi.org/10.25656/01:4683

Farjon, D., Smits, A., & Voogt, J. (2019). Technology integration of pre-service teachers explained by attitudes and beliefs, competency, access, and experience. *Computers & Education, 130*, 81–93. https://doi.org/10.1016/j.compedu.2018.11.010

Fisher, D. M., & Waller, L. R. (2013). The 21st century principal: A study of technology leadership and technology integration in Texas K-12 schools. *The Global ELearning Journal, 2*(4), 1–44.

Fullan, M. (1994). Coordinating top-down and bottom-up strategies for educational reform. *Systemic reform: Perspectives on personalizing education*, 7–24.

Fütterer, T., Scheiter, K., Cheng, X., & Stürmer, K. (2022). Quality beats frequency? Investigating students' effort in learning when introducing technology in classrooms. *Contemporary Educational Psychology, 69*, Article 102042. https://doi.org/10.1016/j.cedpsych.2022.102042

Garson, G. D. (2009). *Structural equation modeling example using WinAMOS: The Wheaton Study*.

Gelman, A. (2007). Struggles with survey weighting and regression modeling. *Statistical Science, 22*(2), 153–164. https://doi.org/10.1214/088342306000000691

Ghadi, M. Y., Fernando, M., & Caputi, P. (2013). Transformational leadership and work engagement: The mediating effect of meaning in work. *The Leadership & Organization Development Journal, 34*(6), 532–550. https://doi.org/10.1108/LODJ-10-2011-0110

Gillet, N., Fouquereau, E., Bonnaud-Antignac, A., Mokounkolo, R., & Colombat, P. (2013). The mediating role of organizational justice in the relationship between transformational leadership and nurses' quality of work life: A cross-sectional questionnaire survey. *International Journal of Nursing Studies, 50*(10), 1359–1367. https://doi.org/10.1016/j.ijnurstu.2012.12.012

Grant, D. G. (2019). Predicting Web 2.0 use among US teens—expanding the power of the skill, will and tool model. *British Journal of Educational Technology, 50*(6), 3405–3419. https://doi.org/10.1111/bjet.12745

Grissom, J. A., Egalite, A. J., & Lindsay, C. A. (2021). *How principals affect students and schools*. Wallace Foundation. http://www.wallacefoundation.org/principalsynthesis.

Guggemos, J., & Seufert, S. (2021). Teaching with and teaching about technology–Evidence for professional development of in-service teachers. *Computers in Human Behavior, 115*, Article 106613. https://doi.org/10.1016/j.chb.2020.106613

Harris, A. (2013). Distributed leadership: Friend or foe? *Educational Management Administration & Leadership, 41*(5), 545–554. https://doi.org/10.1177/1741143213497635

Hitt, D. H., & Tucker, P. D. (2016). Systematic review of key leader practices found to influence student achievement: A unified framework. *Review of Educational Research, 86*(2), 531–569. https://doi.org/10.3102/0034654315614911

Hu, L.-t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1–55.

Huber, S. G. (2021). Schooling and education in times of the COVID-19 pandemic: Food for thought and reflection derived from results of the school barometer in Germany, Austria and Switzerland. In *International studies in educational administration*. Commonwealth Council for Educational Administration & Management (CCEAM)), 49(1).

Huber, S. G., & Helm, C. (2020). COVID-19 and schooling: Evaluation, assessment, and accountability in times of crises—reacting quickly to explore key issues for policy, practice and research with the school barometer. *Educational Assessment, Evaluation and Accountability, 32*(2), 237–270. https://doi.org/10.1007/s11092-020-09322-y

Kish, L., & Frankel, M. R. (1974). Inference from complex samples. *Journal of the Royal Statistical Society: Series B, 36*(1), 1–22. https://doi.org/10.1111/j.2517-6161.1974.tb00981.x

Knezek, G., & Christensen, R. (2008). The importance of information technology attitudes and competencies in primary and secondary education. In *International handbook of information technology in primary and secondary education* (pp. 321–331). Springer.

Knezek, G., & Christensen, R. (2015). *The will, skill, tool model of technology integration: Adding pedagogy as a new model construct*. International Association for Development of the Information Society.

Knezek, G., & Christensen, R. (2016). Extending the will, skill, tool model of technology integration: Adding pedagogy as a new model construct. *Journal of Computing in Higher Education, 28*(3), 307–325. https://doi.org/10.1007/s12528-016-9120-2

Knezek, G., Christensen, R., & Fluke, R. (2003). *April 21–25). Testing a will, skill, tool model of technology integration*. Chicago, IL, USA: Annual Meeting of the American Educational Research Association [Paper presentation].

Kopcha, T. J., & Sullivan, H. (2007). Self-presentation bias in surveys of teachers' educational technology practices. *Educational Technology Research & Development, 55*(6), 627–646. https://doi.org/10.1007/s11423-006-9011-8

Kozma, R. B. (2003). Technology and classroom practices: An international study. *Journal of Research on Technology in Education, 36*(1), 1–14. https://doi.org/10.1080/15391523.2003.10782399

Laschou, S., Kollias, V., & Karasavvidis, I. (2018). How do transformational principals view ICT as a means for promoting educational innovations? A descriptive case study focusing on twenty-first century skills. In *Research on e-learning and ICT in education* (pp. 43–67). Springer. https://doi.org/10.1007/978-3-319-95059-4_3.

Leithwood, K. (2012). *The Ontario leadership framework 2012*. Retrieved from the Institute for Education Leadership website.

Leithwood, K. (2017). The Ontario leadership framework: Successful school leadership practices and personal leadership resources. In K. Leithwood, J. Sun, & K. Pollock (Eds.), *How school leaders contribute to student success: The four paths framework* (pp. 31–43). Springer. https://doi.org/10.1007/978-3-319-50980-8_3.

Little, T. D., Rhemtulla, M., Gibson, K., & Schoemann, A. M. (2013). Why the items versus parcels controversy needn't be one. *Psychological Methods, 18*(3), 285. https://doi.org/10.1037/a0033266

Marsh, H. W., Lüdtke, O., Nagengast, B., Morin, A. J. S., & Davier, M. von (2013). Why item parcels are (almost) never appropriate: Two wrongs do not make a right—camouflaging misspecification with item parcels in CFA models. *Psychological Methods, 18*(3), 257, 10.1037/a003326610.1037/a0032773.

Maxwell, S. E., & Cole, D. A. (2007). Bias in cross-sectional analyses of longitudinal mediation. *Psychological Methods, 12*(1), 23. https://doi.org/10.1037/a00332660.1037/1082-989X.12.1.23

McLeod, S., & Richardson, J. W. (2011). The dearth of technology leadership coverage. *Journal of School Leadership, 21*(2), 216–240.

McNeish, D. (2017). Multilevel mediation with small samples: A cautionary note on the multilevel structural equation modeling framework. *Structural Equation Modeling: A Multidisciplinary Journal, 24*(4), 609–625. https://doi.org/10.1080/10705511.2017.1280797

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

Morales Velazquez, C. M. (2007). Testing predictive models of technology integration in Mexico and the United States. *Computers in the Schools, 24*(3–4), 153–173. https://doi.org/10.1300/J025v24n03_11

Morris, J., & Chi, M. T. H. (2020). Improving teacher questioning in science using ICAP theory. *The Journal of Educational Research, 113*(1), 1–12.

Munir, F., Nielsen, K., & Carneiro, I. G. (2010). Transformational leadership and depressive symptoms: A prospective study. *Journal of Affective Disorders, 120*(1–3), 235–239. https://doi.org/10.1016/j.jad.2009.03.020

Ng, W. L. (2008). Transformational leadership and the integration of information and communications technology into teaching. *The Asia-Pacific Education Researcher, 17*(1), 1–14.

Niederhauser, D. S., & Lindstrom, D. L. (2018). Instructional technology integration models and frameworks: Diffusion, competencies, attitudes, and dispositions. In J. Voogt, G. Knezek, R. Christensen, & K. W. Lai (Eds.), *Second handbook of information technology in primary and secondary education* (pp. 335–355). Springer international handbooks of education. https://doi.org/10.1007/978-3-319-71054-9_23.

Ninković, S., Florić, O. K., & Momčilović, M. (2023). Multilevel analysis of the effects of principal support and innovative school climate on the integration of technology in learning activities. *Computers & Education*. , Article 104833. https://doi.org/10.1016/j.compedu.2023.104833

Oberski, D. (2014). lavaan. survey: An R package for complex survey analysis of structural equation models. *Journal of Statistical Software, 57*, 1–27. https://doi.org/10.18637/jss.v057.i01

Ottestad, G. (2013). School leadership for ICT and teachers' use of digital tools. *Nordic Journal of Digital Literacy, 8*(1–02), 107–125. https://doi.org/10.18261/ISSN1891-943X-2013-01-02-07

Papaioannou, P., & Charalambous, K. (2011). Principals' attitudes towards ICT and their perceptions about the factors that facilitate or inhibit ICT integration in primary schools of Cyprus. *Journal of Information Technology Education: Research, 10*(1), 349–369.

Pelgrum, W. J., & Anderson, R. E. (Eds.). (1999). *ICT and the emerging paradigm for life-long learning*. IEA.

Petko, D. (2012). Teachers' pedagogical beliefs and their use of digital media in classrooms: Sharpening the focus of the 'will, skill, tool'model and integrating teachers' constructivist orientations. *Computers & Education, 58*(4), 1351–1359. https://doi.org/10.1016/j.compedu.2011.12.013.

Petko, D. (2012). Hemmende und förderliche Faktoren des Einsatzes digitaler Medien im Unterricht: Empirische Befunde und forschungsmethodische Probleme. In R. Schulz-Zander, B. Eickelmann, H. Moser, H. Niesyto, & P. Grell (Eds.), *Jahrbuch Medienpädagogik 9*. VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-94219-3_3.

Petko, D., Egger, N., Cantieni, A., & Wespi, B. (2015). Digital media adoption in schools: Bottom-up, top-down, complementary or optional? *Computers & Education, 84*, 49–61. https://doi.org/10.1016/j.compedu.2014.12.019.

Petko, D., & Prasse, D. (2018). Exploring the impact of stakeholder engagement on the integration of educational technology in elementary schools: Expanding the will-skill-tool model with contextual variables. *Association for the Advancement of Computing in* (pp. 1068–1074). Education (AACE.

Petko, D., Prasse, D., & Cantieni, A. (2018). The interplay of school readiness and teacher readiness for educational technology integration: A structural equation model. *Computers in the Schools, 35*(1), 1–18. https://doi.org/10.1080/07380569.2018.1428007.

Podsakoff, P. M., MacKenzie, S. B., Moorman, R. H., & Fetter, R. (1990). Transformational leader behaviors and their effects on followers' trust in leader, satisfaction, and organizational citizenship behaviors. *The Leadership Quarterly, 1*(2), 107–142.

Pozas, M., & Letzel, V. (2021). "Do you think you have what it takes?"–Exploring predictors of pre-service teachers' prospective ICT use. *Technology, Knowledge and Learning, 1–19*. https://doi.org/10.1007/s10758-021-09551-0

Puentedura, R. R. (2012). *The SAMR model: Background and exemplars*. http://www.hippasus.com/rrpweblog/archives/2012/08/23/SAMR_BackgroundExemplars.pdf.

Ruloff, M., & Petko, D. (2022). School principals' educational goals and leadership styles for digital transformation: results from case studies in upper secondary schools. *International Journal of Leadership in Education*, 1–19. https://doi.org/10.1080/13603124.2021.2014979.
Sailer, M., Schultz-Pernice, F., & Fischer, F. (2021). Contextual facilitators for learning activities involving technology in higher education: The C♭-model. *Computers in Human Behavior, 121*, Article 106794. https://doi.org/10.1016/j.chb.2021.106794
Sailer, M., Stadler, M., Schultz-Pernice, F., Franke, U., Schöffmann, C., Paniotova, V., … Fischer, F. (2021). Technology-related teaching skills and attitudes: Validation of a scenario-based self-assessment instrument for teachers. *Computers in Human Behavior, 115*, Article 106625. https://doi.org/10.1016/j.chb.2020.106625
Sasota, R. S., Cristobal, R. R., Sario, I. S., Biyo, J. T., & Magadia, J. C. (2021). Will–skill–tool (WST) model of technology integration in teaching science and mathematics in the Philippines. *Journal of Computers in Education, 8*(3), 443–464. https://doi.org/10.1007/s40692-021-00185-w
Sawyerr, A., & Agyei, D. D. (2022). Mathematics teachers' use of ICT in classroom instruction: Exploring the will-skill-tool-pedagogy model in the Ghanaian context. *Education and Information Technologies*, 1–20. https://doi.org/10.1007/s10639-022-11234-x
Scheel, T. E., Otto, K., Vahle-Hinz, T., Holstad, T., & Rigotti, T. (2019). A fair share of work: Is fairness of task distribution a mediator between transformational leadership and follower emotional exhaustion? *Frontiers in Psychology, 10*, 2690. https://doi.org/10.1007/s40692-021-00185-w
Schmid, M., Brianza, E., & Petko, D. (2020). Developing a short assessment instrument for Technological Pedagogical Content Knowledge (TPACK. xs) and comparing the factor structure of an integrative and a transformative model. *Computers & Education, 157*, 103967. https://doi.org/10.1016/j.compedu.2020.103967.
Schmitz, M. L., Antonietti, C., Cattaneo, A., Gonon, P., & Petko, D. (2022). When barriers are not an issue: Tracing the relationship between hindering factors and technology use in secondary schools across Europe. *Computers & Education, 179*, 104411. https://doi.org/10.1016/j.compedu.2021.104411.
Seyal, A. H. (2015). Examining the role of transformational leadership in technology adoption: Evidence from Bruneian technical & vocational establishments (TVE). *Journal of Education and Practice, 6*(8), 32–43.
Shattuck, G. (2010). Understanding school leaders' role in teachers' adoption of technology integration classroom practices. In *Educational media and technology yearbook* (pp. 7–28). Springer. https://doi.org/10.1007/978-1-4419-1516-0_2.
Spillane, J. P. (2005). Distributed leadership. *The Educational Forum, 69*(2), 143–150. https://doi.org/10.1080/00131720508984678
Stapleton, L. M., McNeish, D. M., & Yang, J. S. (2016). Multilevel and single-level models for measured and latent variables when data are clustered. *Educational Psychologist, 51*(3–4), 317–330. https://doi.org/10.1080/00461520.2016.1207178
Stegmann, K. (2020). Effekte digitalen Lernens auf den Wissens- und Kompetenzerwerb in der Schule. *Zeitschrift für Padagogik, 2/2020*. https://doi.org/10.3262/ZP2002174
Venezky, R. L., & Davis, C. (2002). *Quo vademus? The transformation of schooling in a networked world.* oecd/ceri Paris.
Vermeulen, M., Kreijns, K., van Buuren, H., & van Acker, F. (2017). The role of transformative leadership, ICT-infrastructure and learning climate in teachers' use of digital learning materials during their classes. *British Journal of Educational Technology, 48*(6), 1427–1440, 1427–1440.10.1111/bjet.12478.
Vermeulen, M., van Acker, F., Kreijns, K., & van Buuren, H. (2015). Does transformational leadership encourage teachers' use of digital learning materials. *Educational Management Administration & Leadership, 43*(6), 1006–1025. https://doi.org/10.1177/1741143214535749
Wekerle, C., Daumiller, M., & Kollar, I. (2022). Using digital technology to promote higher education learning: The importance of different learning activities and their relations to learning outcomes. *Journal of Research on Technology in Education, 54*(1), 1–17. https://doi.org/10.1080/15391523.2020.1799455
Wiggins, B. L., Eddy, S. L., Grunspan, D. Z., & Crowe, A. J. (2017). The ICAP active learning framework predicts the learning gains observed in intensely active classroom experiences. *AERA Open, 3*(2), Article 2332858417708567. https://doi.org/10.1177/2332858417708567
Winship, C., & Radbill, L. (1994). Sampling weights and regression analysis. *Sociological Methods & Research, 23*(2), 230–257. https://doi.org/10.1177/0049124194023002004
Yamamoto, Y., & Yamaguchi, S. (2019). Relationships between ICT implementation at schools and factors related to transformational leadership: A case of primary school in Mongolia. *International Journal of Education and Development using Information and Communication Technology, 15*(2), 45–61.
Zigler, C. K., & Ye, F. (2019). A comparison of multilevel mediation modeling methods: Recommendations for applied researchers. *Multivariate Behavioral Research, 54*(3), 338–359. https://doi.org/10.1080/00273171.2018.1527676