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Leading digital innovation in schools: the role of the open innovation mindset

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ABSTRACT

Schools' digitalization requires a shift of stakeholders' mindsets, specific forms of leadership, and strategic knowledge management to deal with current and future educational challenges. The relationship between school leaders' open innovation mindset, transformational leadership, knowledge management practices, and the effects on digital innovation are presented. A random sample of German school leaders is analyzed through confirmatory factor analysis to investigate the construct of school leaders' open innovation mindset followed by structural equation modeling. Results show that digital innovations and transformational leadership in schools require school leaders with an open innovation mindset who foster a collaborative culture of knowledge exchange.

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Introduction

School leaders are central to strategically navigating schools' digitalization while ensuring enhanced teaching, learning, and leadership (Fullan et al., 2023; Håkansson Lindqvist & Pettersson, 2019; Yee, 2000). On the one hand, they are crucial actors in designing internal school structures and providing digital technologies (Dexter, 2008; Vanderlinde et al., 2012). Beyond that, they are central to cultivating a positive, supportive, and collaborative environment with clear and shared visions among the school staff (Kaya-Kasikci et al., 2023). On the other hand, they are important boundary spanners, building bridges between actors outside the school (e.g. authorities and companies) and actors within the school (e.g. teachers) (E. Anderson & Weiner, 2023; Benoliel & Schechter, 2017).

According to Hitt and Tucker (2016) unified model of leadership practices for school effectiveness, the following five practices are essential: (1) establishing and conveying a vision, (2) facilitating educational technology use for students, (3) building professional capacity, (4) creating a supportive organization, and (5) connecting with external partners. Within a systematic review, Dexter and Richardson (2020) analyzed the literature on technology integration in schools, finding that these five leadership practices are also vital for leading digital innovation; however, research examining specific leadership practices on technology integration is still scarce.

Transformational leadership (TL) and networking of school leaders are considered essential prerequisites for integrating digital technologies in schools and their meaningful use, with technology integration in schools being considered an important educational innovation (Backfisch et al., 2021). Further, Yee (2000) found several parallels between technology leadership and TL characteristics that help school leaders ensure information and communication technology (ICT)

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enhances learning, teaching, and work processes management, increases staff commitment, and shifts individual visions to value ICT in education.

Consequently, the most significant conditions for implementing digital media and technology in schools unfold under TL, as it significantly impacts teachers' positive beliefs about digital technology (Schmitz et al., 2023), increases the speed of digital implementations while focusing on educational goals (Ruloff & Petko, 2021), and stimulates knowledge sharing and creation and thus, building a culture of innovation (Afshari et al., 2010). TL is assumed to indirectly affect change and innovation processes, mediated through organizational interaction forms and structures (Leithwood et al., 2020; Leithwood & Sun, 2012).

Besides, most studies stress school leaders' strategic guidance and leadership capabilities to initiate networks, create a culture of change, and realize digital school improvement and change (Bryk, 2010; Hallinger, 2011; Leithwood et al., 2020; Lomos et al., 2023; Timotheou et al., 2023). Notably, schools' knowledge-based innovation processes significantly benefit from external networks and cooperation (Pietsch, Brown, et al., 2023). Additionally, knowledge spaces, that support collaborative knowledge sharing are crucial to make tacit knowledge explicit in schools (Harris, 2008). In this context, school leaders act as boundary spanners, facilitating exchange through TL and knowledge management (KM), thus establishing networks to bring new knowledge into the school, make existing knowledge accessible, and thereby lead schools digital innovation and technology transformation processes (Benoliel & Schechter, 2017).

Research on social networks for school development highlights the increasing role of school leaders' access to social capital and their connectedness within networks as these structures were found to impact leadership practices, their openness toward risk-taking, and the overall innovation climate at the school (Daly & Finnigan, 2010; Leana, 2011; Liou & Daly, 2018). In this background and considering 21st-century developments, digital media tools have become necessary for effective school leadership (Cox & McLeod, 2014). Following Richardson et al. (2019), digital technologies and social media platforms, e.g. Twitter, can be beneficial to increasing school leaders' networking by offering communities of practice, interpersonal connections, access to professional expertise, and research findings. Beyond that, digital media increases information distribution and transparency (Cox & McLeod, 2014) and strengthens the school community by connecting people around shared goals and visions (Richardson et al., 2019; Richardson & Sterrett, 2018).

To date, only a few studies have provided evidence-based practices for educational technology leaders on engaging stakeholders and building productive relationships when leading technological innovation and change in schools (Dexter & Richardson, 2020; McLeod & Richardson, 2011). However, studies on technology integration in schools revealed that there are successful technology leaders who transformed their schools digitally (Hofer et al., 2023; McLeod et al., 2015; Sterrett & Richardson, 2019); it is now to expand the understanding of these individuals' attitudes, mindsets, strategies, and methods to develop implications for school leaders professionalization.

Irrespective of this discussion, Kane (2019) argues that successful digital transformation always starts with a mindset shift at the employee, leadership, and organizational levels, which leads to agility, risk tolerance, experimentation, and collaboration, thereby improving innovation outcomes or leading to their failure (Kouzes & Posner, 2019; Salehi & Asrar, 2022). The relevance of school leaders' and teachers' mindsets was also found to be essential in schools' digital transformation processes (Chua & Chua, 2017; Mac Callum et al., 2014; McLeod et al., 2015). McLeod and Richardson (2013) highlight school leaders' primary responsibility in developing a culture and climate to promote technology learning and "to enact sustained initiatives of communication and education until long-term change mindsets are firmly in place that digital technologies are here to stay, that they are important, and that they will continuously and disruptively foster numerous changes in schooling practices." (p. 255).

On this behalf, school leaders have a superior role in cultivating a positive environment for schools' digital transformations (Kaya-Kasikci et al., 2023), and previous research highlights the

impact of mindsets and beliefs on successful technology integration in schools (P. M. Davies, 2010; Kim et al., 2013; McLeod et al., 2015; Richardson & Sterrett, 2018). Nevertheless, school leaders face challenges requiring professional development and a specific risk mindset to reduce fears of negative consequences and staff resistance (McLeod et al., 2015; Richardson & Sterrett, 2018; Sincar, 2013). According to Chua and Chua (2017), school leaders should further stimulate change for positive mindsets, support network thinking, and develop a shared vision and mission within the school.

However, what constitutes such a mindset and how it affects school digitalization has yet to be researched. The concept of Open Innovation (OI) seems promising for the educational discourse, as it has been proclaimed the key to innovation by promoting an open digital world that enables co-creation among all societal stakeholders through strategic knowledge sharing (Bogers et al., 2019). OI is defined as "a distributed innovation process based on purposefully managed knowledge flows across organizational boundaries" (Chesbrough & Bogers, 2014, p. 12) that primarily addresses an open, distributed mindset of actors, organizations, and involved stakeholders to create and implement new digital technologies (Chesbrough, 2017). In this regard, Salampasis et al. (2015, p. 49) state: "Open innovation is a dynamic organizational mindset that encourages the exploration and exploitation of diverse knowledge inflows and outflows, leading to innovation continuity and incremental organizational change, through the establishment of trustworthy, culturally sensitive and sustainable relationships." Recently, Engelsberger et al. (2022) developed a construct of what constitutes such an OI mindset (OIM), and Slavec Gomezel and Rangus (2019) showed that organizational innovation always starts with such a mindset of leaders. However, whether this also applies to schools and school leaders has not been investigated.

Against this background, our study examines whether and, if so, how school leaders' OI mindset (OIM) promotes digital innovation in schools. Therefore, we rely on the preliminary work of Engelsberger et al. (2022) and examine the effects of such a mindset on TL and digital innovation in schools. Since OI is always about knowledge flows, we consider internal KM within schools to play a central role in whether TL affects digital innovation in schools. Our study aims to contribute to the knowledge field of schools' digital transformation processes by transferring the concept of the OIM to the educational context and investigating school leaders' OIM as an antecedent of TL and, consequently, of digital innovation in schools. We rely on a sample of German school leaders, as in Germany, schools' digitalization, i.e. technical supplies, wireless network availability, and IT support mechanisms, is far behind international standards (ICILS 2018) (Eickelmann et al., 2019). Even though in 2022, a nationwide representative survey of German school leaders revealed that after the COVID-19 Pandemic, technical equipment and its integration in schools increased, adequate assistance and technology support are still deficient (Tulowitzki et al., 2023). Furthermore, school leaders are missing professional and systematic qualification programs that help them not only use digital technologies at their schools but also address those technologies and function as role models and experts in technology integration (Tulowitzki et al., 2023).

Theoretical background

Digital innovation in schools

Hund et al. (2021) define digital innovation as "the creation or adoption, exploration of an inherently unbounded, value-adding novelty (e.g. product, service, process, or business model) through the incorporation of digital technology" (p. 6). Accordingly, digital technology is embedded in digital innovation and goes beyond implementing digital inventions into organizational structures. Consequently, digital innovations require deliberate approaches using technologies to transform those technologies into innovations (Wiesböck & Hess, 2020).

Educational research highlights the need to rethink the impact of digital technologies and participative cultures (Halverson et al., 2018). Furthermore, supporting students' knowledge and

skills acquisition, teachers' professionalization, ensuring inclusion, and organizational and professional practices requires a holistic digital transformation (Kazu & Yalçın, 2022; M. H. Lin et al., 2017; Timotheou et al., 2023). Empirical findings also emphasize the diverse benefits of systematically integrating ICT and digitalization. ICT in education increases schools' organizational agility, supports future innovation, and enriches a variety of teaching and learning methods, thereby supporting the achievement of educational standards (Dörner & Rundel, 2021; Kang, 2021).

However, digital transformation in education leads to pedagogical, didactical, administrative, and policy challenges, which could hinder its success and undermine its benefits (Schmidt & Tang, 2020). Accordingly, implementing technology in schools needs to be holistic, allowing integration into the broader system and advancing the system by considering fundamental changes in pedagogical work, curricula, forms of communication, and social relationships (Lim et al., 2013). Research on technology leadership in schools assigns significant responsibility to the school leaders, their strategic thinking, ICT competencies, and their beliefs and attitudes toward technology integration (Arafeh, 2015; Chang et al., 2008; P. M. Davies, 2010; Richardson et al., 2012; van Niekerk & Blignaut, 2014). McLeod and Richardson (2011) state that *"school leaders who do not understand how to navigate this change will be doing a disservice to their schools and students"* (p. 236), pointing to the need for school transformation in a technology-driven society.

In this regard, school leaders, their mindset, leadership style, and established KM practices are decisive in creating a culture of change, allowing participative development, and exploring new and existing knowledge within and beyond the organization (Dexter & Richardson, 2020).

Knowledge management for digital innovation

While schools have traditionally been weak in knowledge sharing (Fullan, 2002), systematic KM is relevant for their innovation and change processes, especially for digital transformation (Zhao, 2010). According to Chu (2016), KM in schools is "the formulation of the processes in establishing an environment to foster organizational members to create, share, learn and use knowledge comprising experience in the know-how" (p. 1106). In this respect, the KM infrastructure concerns the structure, technology, and culture of the organization (Kılıç & Uludağ, 2021), with processes having the strategic aim of mobilizing the knowledge of all members involved in schooling (Jesacher-Roessler, 2021). For public sector organizations in general, effective knowledge management is necessary to ensure the success of their digital transformation (Alvarenga et al., 2020).

Empirical findings in educational research show the impact of KM on enhanced teaching and learning processes and increased performance (Asad et al., 2022). Especially organizationally managed knowledge-sharing activities allow teachers to express their tacit knowledge, reflect on experiences and observations, and consequently support creativity and knowledge-creation processes, and reduce barriers between schools' different stakeholders (Horng et al., 2005; Rismark & Solvberg, 2011).

On the one hand, knowledge practices at the school level that give orientation, support common knowledge practices, and allow exchange and collaboration within the teachers' community are essential for digital school development (Ilomäki & Lakkala, 2018). On the other hand, social practices and knowledge exchange that go beyond the school level are essential for teachers' professional development and meaningful adoption of technology in teaching (Ley et al., 2022).

Whereas KM is a medium and outcome of innovation focusing on communities of practice and knowledge sharing within and across organizations to overcome structural barriers to innovation processes (Scarbrough, 2003), knowledge transfer practices are a central part of KM in organizations. All communication channels that enable organizations' members to exchange and develop existing knowledge are knowledge transfer practices (Donate & Sánchez de Pablo, 2015). Accordingly, digital transformation and the associated changes in knowledge flows and communication forms make KM a crucial dynamic capability to adapt knowledge transfer practices,

ensure optimized use of technologies, and foster digital innovation (Di Vaio et al., 2021). It increases organizations' abilities to use existing and explore new knowledge by providing conditions and channels for knowledge sharing, donating, and creating (Antunes & Pinheiro, 2020; H.-F. Lin, 2007; Van Den Hooff & Ridder, 2004).

Schools face specific challenges in implementing KM as they often lack financial resources and infrastructures and are confronted with staff's low motivation and missing professionalization (Raudeliuniene et al., 2020). However, strategic leadership offers solutions to those obstacles (Fullan, 2002). Mainly engaged and committed leaders supporting knowledge and learning activities are the driving force of KM practices in organizations (Donate & Sánchez de Pablo, 2015). Moreover, leaders are responsible for creating a communication and social interaction culture that supports members' willingness to share their knowledge (H.-F. Lin, 2007; Van Den Hooff & Ridder, 2004). Specifically, TL behavior significantly impacts knowledge-sharing processes by building trust, offering inspiration, and increasing motivation to participate in knowledge exchange activities (Al-Husseini & Elbeltagi, 2018).

Transformational leadership for digital innovation

Transformational Leadership (TL) is one of educational research's most intensively investigated leadership approaches and significantly affects change and innovation processes (Hallinger, 2003; Khalili, 2016). Generally, the effects of TL on school outcomes are indirect, as TL affects organizational conditions and, consequently, teaching and learning outcomes (Leithwood & Jantzi, 2000; Leithwood & Sun, 2012). Outside of education, KM practices have been found to have a mediating function, that is-TL improves KM, which improves organizational performance (Birasnav, 2014; Kılıç & Uludağ, 2021).

One decisive factor in TL is the increase in employees' active participation in development processes and the decrease in leaders' direct and instructional management and control methods (Hallinger, 2003). Accordingly, leaders are facilitators of diverse development processes on individual and organizational levels. Following Bass and Riggio (2010), they inspire and help followers to grow and engage through empowerment and goal alignment. Furthermore, TL supports leaders in creating a clear, shared vision and becoming positive, motivating role models (Leithwood & Jantzi, 2006). The central aim of TL is to change followers' attitudes and aspirations, support individual development, and enhance sustainable innovation. Especially during critical periods, e.g. digital disruptions, TL skills are critical to educational development (Yang, 2014).

Looking at the postulated requirements and leadership strategies to support digital transformation in education (Dexter & Richardson, 2020), TL offers concrete strategies for creating those conditions and requirements (Dexter, 2008; Schmitz et al., 2023), ensures the active integration of staff into creation and collaboration processes (Franciosi, 2012), and thereby helps to sustainably integrate technologies in schools (Ruloff & Petko, 2021). Furthermore, leading technology integration in schools benefits from distributed leadership approaches that provide diverse sources of knowledge and draw on experts (Sheppard & Brown, 2014).

Leaders' Open Innovation Mindset: an antecedent for digital Innovation

However, how leadership is enacted depends heavily on the implicit assumptions and theories leaders have about themselves, that is, their mindset (Kouzes & Posner, 2019). Generally, a mindset represents a multidimensional combination of beliefs or implicit theories activated in the interaction between a sensemaker's mind and its context (Rauch, 2021). Mindsets are domain-specific; thus, for digitalization, school leaders' beliefs about leading digitalization are, for example, more relevant than beliefs about good leadership (Hughes, 2015). Further, mindsets are distal predictors of performance, meaning that several attributes, contexts, and processes mediate the relationships between mindsets and outcomes (Burnette et al., 2013). Digitalization

requires a specific mindset to successfully lead digital transformation, as it frames how leaders think about and manage a business, resulting in opening or closing opportunities (Kane, 2019).

On this behalf, school leaders' mindsets are vital to support school development on various levels. They can be described as the fundament of establishing an open, collaborative, and risk and failure-tolerant culture within the school (Tirri et al., 2021).

According to Hofer et al. (2023), transforming learning and technology leadership in education depends on innovative educators with interconnected mindsets, skills, and competencies. Further, Dexter and Richardson (2020) have shown that school leadership that promotes technology integration and digitalization must be characterized above all by participation, collaboration, co-creation, and regular knowledge sharing with all stakeholders. Sterrett and Richardson (2019) claim that technology integration in schools strongly depends on leaders' ability to empathize with the learning group's needs, foster change, and their willingness to take risks and use opportunities for innovation. Moreover, school leaders' mindsets, their commitment to technically transform their schools, their engagement in learning communities and networks, and their openness to disruptive ideas are vital to learning from success and failure (R. S. Davies & West, 2014; McLeod et al., 2015; Sterrett & Richardson, 2019). Thus, schools' digitalization requires a leadership mindset and actions focusing on active knowledge sharing, participation, and collaboration.

Based on the research on Open Innovation (Chesbrough, 2003, 2006; Chesbrough & Bogers, 2014) and following up the research on risk mindsets for innovation and development (Sterrett & Richardson, 2019), Engelsberger et al. (2022) refer to such a mindset as an Open Innovation Mindset (OIM). The OIM comprises four capabilities: openness, creativity, a positive attitude toward knowledge sharing and sourcing (KSS), and risk and failure tolerance (Engelsberger et al., 2022). Openness refers to being open to change and curious about experimenting (Slavec Gomezel & Rangus, 2019). Creativity means solving problems and generating products by recombining knowledge to create ideas, integrating knowledge into systems, and adapting systems to inventions (Bogers et al., 2019). A positive attitude toward KSS describes the willingness to accept, work with, and realize external and disruptive ideas (von Briel & Recker, 2017). Risk and failure tolerance, the last facet of OIM, encompasses the ability to deal with uncertainties, failure, and willingness to take risks (Engelsberger et al., 2022).

Theoretical model and research hypotheses

Based on the previous discussion, we propose that school leaders' OIM is an antecedent of TL that indirectly influences digital innovation. TL acts as a predictor of KM and digital innovation in schools. KM is mediating the relationship between transformational leadership and digital innovation (Figure 1).

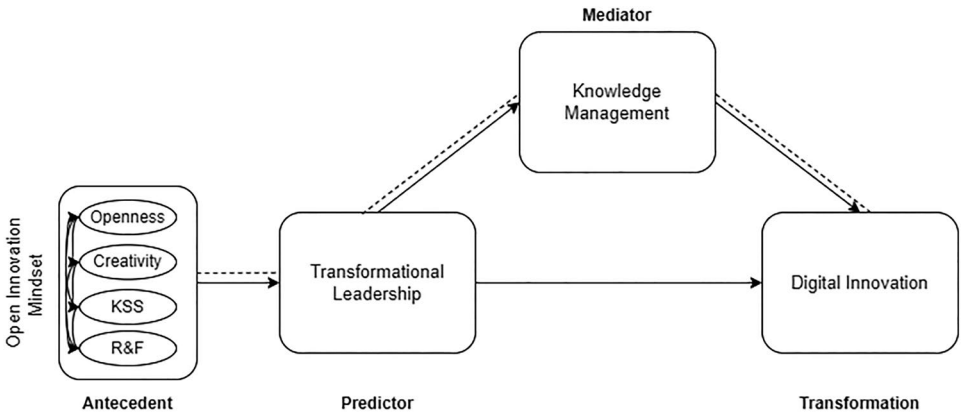

Figure 1. Conceptual model. Note: dotted lines = indirect effects.

The following hypotheses guided our study:

1. H1: A school leader's OIM affects his or her TL practices.
2. H2: TL positively impacts the implementation of digital innovations in schools.
3. H3: TL positively impacts KM practices in schools.
4. H4: KM positively impacts the implementation of digital innovation in schools.
5. H5: TL indirectly impacts the implementation of digital innovation in schools mediated by KM.
6. H6: A school leader's OIM indirectly affects the implementation of digital innovation through TL and KM in schools.

Methodology

Survey procedure

The data was collected within the Leadership in German Schools (LineS) study a biennial survey of German school leaders launched in 2019 (Cramer et al., 2021). For our analysis, data was collected from August to November 2021, explicitly emphasizing innovation. Forsa, the German Institute for Social Research and Statistical Analysis, organized and performed participant acquisition and questionnaire provision. A random sample of 1000 people aged 14 years and older surveyed daily resulted in the identification of $N = 411$ school leaders, a nationally representative sample for Germany. All participants were given access to an online questionnaire, with data collection following ESOMAR standards. The online format allowed random allocations of items as sections, filter questions, question blocks, and varying question formats such as closed-, half-open-, and open-ended questions. Furthermore, the variation of item wording and randomly rotated and scrambled item blocks across individual surveys minimized common method bias (Podsakoff et al., 2012).

Sample

The sample consists of 411 German school leaders; 103 participated in the first two waves of measurement, and 308 were subsequently recruited as a refreshment sample for the third wave of measurement. 247 (60.1%) of participants were female, 163 (39.7%) were male, and 0.2% were divers. Most of the school leaders were in the age between 50 and 59 (207, 50.4%), 106 were in the age between 40 to 49 (25.8%), 82 (20%) of the school leaders were 60 years old and above, and only 16 (3.9%) were 39 years old and younger. 91% of the participants worked at public schools, 8.5% at private schools. 15.3% of the school leaders worked at schools located in a town (less than 3000 inhabitants), 25.8% in a village (3000 – 15 000 inhabitants), 34.3% in a small city (15 000—100 000 inhabitants), 18.2% in bigger cities (100 000—1 000 000 inhabitants), and 6.1% in a metropolis (more than 1 000 000 inhabitants). The participants also provided information on the type of school they were leading. Of our sample, 53% worked in primary education, 38.2% at secondary schools, and 8.5% at other schools, including special-needs schools.

Measures

Due to our study's different context and culture, all items from previous investigations were translated and adapted accordingly (see Appendix). **The Open innovation mindset (OIM**) measures four dynamic capabilities of school leaders: openness, creativity, positive attitude toward knowledge sharing and sourcing (KSS), and risk and failure tolerance (R&F). Based on their factor loadings, we carefully selected eight items from Engelsberger et al. (2022) OIM scale to measure openness, creativity, and R&F. Two items measured **openness** ($\omega = 0.771$). An example item was: "I see myself as someone who is original and comes up with new ideas". We used three items each to measure **creativity** ($\omega = 0.858$) and **R&F** ($\omega = 0.646$)**;** an example item of creativity

was: "I often have new and innovative ideas." and an example item of R&F was: "I believe that failure is a necessary part of success". For **KSS** ($\omega = 0.836$), we used three items based on Antons et al. (2017) that measure attitudes toward collecting and sharing knowledge; an example item was "I look for opportunities to exchange with persons having a different knowledge background".

To measure **transformational leadership** ($\omega = 0.688$), we used four items from the Multifactor Leadership Questionnaire (MLQ; (Bass & Avolio, 1995), indicating idealized influence, inspirational motivation, intellectual stimulation, and individualized consideration. We modeled the construct unidimensional following Heinitz et al. (2005). An example item was: "I help my schools' teachers to develop their strengths". Following the research on knowledge-oriented leadership (Donate & Sánchez de Pablo, 2015), we used six items to measure **knowledge management** ($\omega = 0.828$) in schools by investigating knowledge transfer practices during the last 12 months. An example item is: "Self-organized groups existed at the school in which teachers could learn from each other and exchange knowledge, e.g. communities of practice". Answers for all the above items were given on a unipolar verbal Likert rating scale to measure the intensity of specific characteristics, going from 1: fully disagree to 4: fully agree.

The model's dependent variable, **digital innovation**, was measured by a multi-step procedure based on the European Community Innovation Survey (Behrens et al., 2017). To avoid misconceptions when measuring innovation, we initially defined the term. Accordingly, innovations are new to the schools' pedagogical work but can be known and established in the educational sector (OECD/Eurostat, 2018). First, the participants answered on a binary-coded variable (0= no, innovations have not been introduced; 1= yes, innovations have been introduced) if they introduced any process innovation in the schools within the last 12 months; "Have any process innovations been introduced at your school in the last 12 months?". Second, the respondents named the top three innovations in open fields. Third, the participants ordered those innovations based on relevance and the extent of the innovations' value within their school. Fourth, the notified innovations were rated regarding their incremental or radical nature on a scale from 1 (incremental innovation- improving, supplementing, or adapting existing strategies) to 10 (radical innovation- implementing something entirely new for the school). 78.8% of the schools introduced any innovation, 19.2% did not introduce innovations, and two percent of answers were missing.

For our analyses, we binary-coded the open-ended responses from step two (0= no digital innovation, 1= digital innovation), with digital innovation referring to the appropriate use of digital media in teaching and learning. Digital innovations compromised, e.g. the integration of tablets in the classrooms, setting up digital tools for parental involvement, and the creation of virtual classrooms, but mainly followed level 1 (replacement) and level 2 (augmentation) of the substitution augmentation modification redefinition (SAMR) model (Hamilton et al., 2016; Puentedura, 2006). Based on this, we created a variable indicating the radicalness (or disruptiveness) of the digital innovations (1= incremental to 10= radical), with "no digital innovation" coded as 0. Accordingly, the variable we use is a ratio scale that contains an absolute or true zero (Stevens, 1946), indicating the total absence of digital innovations in a given school.

Analytical strategy

We used structural equation modeling (SEM) to examine our hypotheses. We applied Harman's one-factor test to test for common method bias (Harman, 1960). The total variance extracted by one factor was far below the 50% threshold (15.88%), ensuring no common method bias in our study (Lance et al., 2010). The total of missing data was 1.5%. Data analysis was performed in Mplus version 8.3 (Muthen & Muthen, 2017) using the diagonally weighted least squares estimator (WLSMV) to ensure the assumption of a normal latent distribution of the categorically and ordinally observed data (Brauer et al., 2023).

Before estimating the SEM, construct validation of the measurement models was performed through confirmatory factor analysis (CFA). Regarding the complexity and novelty of the latent

construct OIM in the educational context, we examined its factor structure progressively by computing several CFAs. The procedure allowed us to verify the predicted factor structure, avoid cultural and construct bias, and assess the measurement model for further analyses (J. C. Anderson & Gerbing, 1992).

To evaluate the model's goodness of fit, we used the following fit indices and ranges: standardized root mean square residual (SRMR, <0.08), the root mean square error of approximation (RMSEA, <0.06, 90% CI < 0.06), the comparative fit index (CFI, >0.95), and the standardized factor loadings (Schermelleh-Engel & Moosbrugger, 2003). As we estimated an indirect path model, we further tested the robustness of the mediation effects through bootstrapped mediation analysis that provides 95% bias-corrected bootstrap confidence intervals with 2,000 bootstrap replications (Hayes, 2018; Preacher & Hayes, 2008). Indirect effects are significant if the 95% confidence intervals (CIs) do not include zero (Hayes, 2018).

Results

Table 1 presents the means (*M*), the standard deviation (*SD*), and the correlations of the model variables. The means of the OIM facets show that, among the surveyed school leaders, a positive attitude toward knowledge sharing and sourcing ($M = 3.57$) is stronger pronounced than their openness ($M = 2.99$) and creativity ($M = 3.20$) and their risk and failure tolerance ($M = 2.96$). Furthermore, the correlation matrix shows that the four facets are statistically significantly correlated, underlining that these variables are related and form the OIM. TL is used often by the surveyed school leaders ($M = 3.22$, $SD = .44$). Further, the statistically significant correlations between TL, the OIM facets, and KM indicate a relationship between the constructs (r between .233 and 1.000, $p < .05$). KM is maintained by the school leaders moderately ($M = 2.99$, $SD = .59$) and is the only variable statistically correlated with digital innovation ($r = .171$ $p < 0.05$). Digital innovation has a mean of $M = 3.28$ (SD = 3.77), meaning that the implemented innovations, on average, were rated as incremental rather than radical.

Confirmatory factor analysis

The results of the measurement model estimations are depicted in Table 2. Regarding the OIM, we tested five models: 1. single-factor model; 2. four-factor first-order model; 3. four-factor second-order model; 4. three-factor first-order model; and 5. three-factor second-order model. In models 2 and 3, we followed Engelsberger et al. (2022) and modeled four distinct factors: openness, creativity, KSS, and R&F. However, we found a high correlation between the facet's openness and creativity ($r = 1.00$, $p < .001$), a fact that is well-known from research on personality traits (Karwowski & Lebuda, 2016; King et al., 1996). Consequently, we combined the items of both facets into one factor (OC_G) and tested an alternative first-order (model 4) and a second-order model (model 5). Both models fitted the data equally well (RMSEA= 0.06, CFI= 0.97, SRMR= 0.04); introducing

Table 1. Means, standard deviations and correlations of all variables.

	Variable	M	SD	1	2	3	4	5	6
1	Openness	2.99	.63	I					
2	Creativity	3.20	.51	**1.000**	I				
3	KSS	3.57	.41	**0.453**	**0.547**	I			
4	R&F	2.96	.51	**0.587**	**0.587**	**0.498**	I		
5	TL	3.22	.44	**0.528**	**0.647**	**0.554**	**0.576**	I	
6	KM	2.99	.59	**0.295**	**0.352**	**0.287**	**0.233**	**0.435**	I
7	Innovation	3.28	3.77	−0.031	−0.037	0.063	0.010	0.021	**0.171**

Note: KSS = Positive Attitude Toward Knowledge Sharing and Sourcing, R&F = Risk and Failure Tolerance, TL = Transformational Leadership, KM = Knowledge Management, bold correlations statistically significant at least at $p < 0.05$.

Table 2. Model fit indices.

Model	CFI	SRMR	RMSEA
1. OIM Single-factor model	0.87	0.10	0.15
2. OIM Four-factor model	0.97	0.04	0.06
3. OIM Four-factor second-order model	0.97	0.05	0.07
4. OIM Three-factor first-order model	0.97	0.04	0.06
5. OIM Three-factor second-order model	0.97	0.04	0.06
6. TL Single-factor model	1.00	0.01	0.00
7. KM Single-factor model	0.97	0.03	0.08

Note: OIM = Open Innovation Mindset, TL = Transformational Leadership, KM = Knowledge Management.

Table 3. Standardized direct effects.

Direct effects	β	SE	*p*
OC_G → TL	0.362	0.095	0.000
KSS → TL	0.297	0.094	0.002
R&F → TL	0.204	0.104	0.050
TL → Digital Innovation	−0.096	0.075	0.201
TL → KM	0.476	0.059	0.000
KM → Digital Innovation	0.216	0.074	0.003

Note: OC_G = Openness&Creativity, KSS = Positive Attitude Toward Knowledge Sharing and Sourcing, R&F = Risk and Failure Tolerance, TL = Transformational Leadership, KM = Knowledge Management.

Table 4. Standardized indirect effects.

Indirect Effects	β	95% CI	SE	*p*
TL → KM → Digital Innovation	0.103	0.032 – 0.198	0.041	0.012
OC_G → TL → KM → Digital Innovation	0.037	0.010 – 0.078	0.019	0.045
KSS → TL → KM → Digital Innovation	0.031	0.009 – 0.076	0.016	0.059
R&F → TL → KM → Digital Innovation	0.021	0.003 – 0.062	0.015	0.172

Note: OC_G = Openness&Creativity, KSS = Positive Attitude Toward Knowledge Sharing and Sourcing, R&F = Risk and Failure Tolerance, TL = Transformational Leadership, KM = Knowledge Management.

a second-order factor did not improve the measurement model, so we followed Marsh et al. (2014) and rejected model 5. The fit indices of KM (RMSEA= 0.08, CFI= 0.97, SRMR= 0.03) and TL (RMSEA= 0.00, CFI= 1.00, SRMR= 0.01) approved a good measurement quality (Table 2).

In the next step, we tested the conceptual model by estimating the SEM. The fit indices of the structural model confirmed a moderate but acceptable fit to the data ($\chi 2 = 315.403$, $df = 199$, RMSEA= 0.04, CFI= 0.98, SRMR= 0.05). The standardized direct effects are listed in Table 3, and the indirect effects in Table 4.

As all OIM facets positively impact TL (OC_G on TL: $\beta = 0.369$, SE = 0.098, $p < 0.000$; KSS on TL: $\beta = 0.204$, SE = 0.091, $p < 0.025$; R&F on TL: $\beta = 0.301$, SE = 0.119, $p < 0.011$), H1 was accepted: school leaders' OIM is an antecedent to their TL behavior. Hypothesis H2 was rejected as TL does not directly affect digital innovation ($\beta = -0.076$, SE = 0.070, $p < 0.280$). However, TL significantly affects KM ($\beta = 0.448$, SE = 0.069, $p < 0.000$), which, in turn, positively impacts digital innovation ($\beta = 0.209$, SE = 0.070, $p < 0.003$). On this behalf, hypotheses H3 and H4 were supported. Even though we could not find a direct relationship between TL and digital innovation, we found evidence for hypothesis H5. R^2 was 0.514 for TL, 0.226 for KM, and 0.036 for digital innovation.

Mediation analysis

The indirect path from TL on digital innovation, mediated by KM, shows a statistically significant effect of $\beta = 0.103$ [95% CI: 0.032 – 0.198]. Besides, the indirect paths revealed statistically significant effects from OC_G *via* TL and KM on digital innovation ($\beta = 0.037$, 95% CI:

0.010 – 0.078), from KSS *via* TL and KM on digital innovation (β = 0.031, 95% CI: 0.009 – 0.076), and from R&F *via* TL and KM on digital innovation (β = 0.021, 95% CI: 0.003 – 0.062). Based on these findings, H6 was accepted. All three dimensions that form the OIM have a statistically significant indirect effect on implementing digital innovation in schools. Implementing digital innovation in schools depends on KM, which relies on school leaders' TL. The OIM functions as an antecedent and necessary capability for TL, positively impacting KM and thus enhancing digital innovation processes in schools.

Discussion

TL and KM are vital for successfully leading digital transformation. Besides, previous research on organizational innovation processes underlines the relevance of leaders' mindsets and all those involved in the transition process to overcome the obstacles to sustainable and integrated developments. Research evidence on school leaders' mindsets and the resulting impact on digital innovation in schools is still scarce. However, theory assumes that the mindset of school leaders is essential for positive educational change (Gallagher & Thordarson, 2018; Hofer et al., 2023) and qualitative research on technology integration in schools highlights the relevance of school leaders as technology leaders who pave the way to schools' digital and technological transformation (Cox & McLeod, 2014; P. M. Davies, 2010; McLeod & Richardson, 2011; Sterrett & Richardson, 2019; Yee, 2000). Accordingly, a risk mindset, fostering a culture of change, strong communication, and professional networks, as well as shared vision-setting were identified as essential leadership behaviors for technology integration (McLeod et al., 2015; Richardson & Sterrett, 2018; Tirri et al., 2021; Yee, 2000).

By transferring the concept of the OIM to the educational context and linking it with TL and KM practices, our study contributes to the research field on schools' digitalization and educational technology leadership. The OIM of school leaders is a dynamic capability, defined as the capacity to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments characterized by deep uncertainty (Bogers et al., 2019). This capability is comprised of three facets: openness and creativity, a positive attitude towards knowledge sharing and sourcing, and risk and failure tolerance.

In line with research findings on the impact of an OIM on innovation outcomes (Engelsberger et al., 2022), our study's results show that school leaders' OIM indirectly positively impacts digital innovation in schools. More precisely, all three facets of the OIM are essential, enabling school leaders to create the conditions for implementing digital innovations. Beyond that, we found that the OIM is a crucial precondition for TL in schools, supporting the idea that such a leadership style promotes collaboration and knowledge transfer within the organization (Dexter & Richardson, 2020) and largely depends on a school leaders' mindset. This finding is in line with previous studies on technology school leaders, who were found to be open to taking risks and engaging others within their organization to develop and test new approaches to technology integration (Hofer et al., 2023; McLeod et al., 2015; Sterrett & Richardson, 2019).

The indirect effect of TL on digital innovation, mediated by KM practices, highlights the complexity of schools' digital transformation processes. This finding is in line with the research of Schmitz et al. (2023), stating that TL distally predicts technology integration but is mediated by certain variables. Moreover, our findings support previous findings on successful technology leadership as a distributed and essentially TL approach (Dexter, 2008; Sheppard & Brown, 2014; Yee, 2000). Furthermore, the implemented digital innovations were predominantly incremental changes on the substitution and augmentation level, functioning as substitutions that generated functional improvements (Hamilton et al., 2016).

On the one hand, our study proves the relevance of KM practices as a mediating variable for implementing digital innovation. On the other hand, our findings support the vital role of TL in overcoming barriers to KM practices (Al-Husseini & Elbeltagi, 2018), which in turn

enhances the success of schools' digital transformation (Alvarenga et al., 2020). Therefore, solely TL does not significantly facilitate digital innovation; instead, it fosters KM practices that create a participative culture of innovation and consequently leads to the implementation of digital innovation. These results reflect the findings of previous studies on technology leadership in education, highlighting the relevance of organizational KM (Ilomäki & Lakkala, 2018; Rismark & Solvberg, 2011) and social networks within and across schools for innovative technology integration (Daly & Finnigan, 2010; Leana, 2011; Liou & Daly, 2018). Furthermore, our findings support the vital role of school leaders as knowledge brokers who span the boundaries between the stakeholders of the learning organization by facilitating, supporting, and visioning technology transformation (Chang et al., 2008; Cox & McLeod, 2014; Richardson et al., 2012; 2019; van Niekerk & Blignaut, 2014).

Limitations

Although our study has provided many insights into the design and organization of schools' digital innovation, it is necessary to note the following limitations. Due to the cross-sectional nature of our data, the results are not generalizable, and causality can only be assumed. As all the participants were German school leaders, neither a comparison to other contexts nor the perceptions of other school stakeholders, e.g. teachers and students, were measured to contrast the self-reports. Considering the relevance of peoples' mindsets for digitalization, it is necessary to assess teachers' and students' mindsets too to develop an extensive strategy for digitalization. Furthermore, measuring the development of school leaders' OIM over time and the resulting impacts on TL, KM, and digital innovations is required. Following the research on measuring personality traits and considering the length of the scale we used to assess the facets (Karwowski & Lebuda, 2016), it is unsurprising that the scales of openness and creativity could not be divided empirically. The low value of the explained variance of the dependent variable indicates the need for further research on impact factors on digital innovation. It is relevant to note, however, that despite this low R^2 and the distal nature of the OIM, significant indirect effects were still observable.

Conclusion and implications

The findings of our study support the assumption that digital transformation processes start with the mindset of the involved people and require a shift in thinking to improve and transform existing paradigms (Kane, 2019; McLeod et al., 2015; McLeod & Richardson, 2011; Richardson & Sterrett, 2018). Concerning the challenges schools face when digitally transforming pedagogical methods, forms of teaching, and leadership and management tools (Schmidt & Tang, 2020), school leaders with a pronounced OIM can address those challenges more fundamentally, facilitating conditions for a participative and knowledge-based digital innovation process.

Whereas school leaders have a central role in navigating schools' digitalization (P. M. Davies, 2010; Dexter, 2008; Håkansson Lindqvist & Pettersson, 2019; McLeod & Richardson, 2011; Vanderlinde et al., 2012), investigating school leaders' OIM as the root of their leadership behavior allows us to derive practical implications for technology leadership practices and school leaders' professionalization. Accordingly, we recommend that professionalization programs emphasize fostering dynamic capabilities, i.e. openness and creativity, KSS, and R&F, thereby strengthening school leaders' OIM and attitudes toward digital innovation and strategic technology integration. As previous research highlighted the complexity of technology leadership (Arafeh, 2015), opportunities to develop mindsets complemented by technology knowledge, skills, and specific leadership approaches are vital to creating holistic, sustainable, and flexible transformations (Hofer et al., 2023).

Furthermore, school leaders must establish a participative culture through TL and KM practices to develop digital innovations strategically interlaced with educational goals. Nevertheless,

digital technologies and their diverse applications in schools' exploration, creation, and communication processes are simultaneously the outcome and source of innovation and should be integral components of school development.

Our research thus adds to the existing evidence on technology leadership in education but also highlights the importance of an according OIM on the part of school leaders: on the one hand, school leaders who are instrumental in integrating technology in schools must be willing to take risks (McLeod et al., 2015; Sterrett & Richardson, 2019), be creative (R. S. Davies & West, 2014), require access to social capital via professional networks (Daly & Finnigan, 2010; Liou & Daly, 2018), and act as knowledge brokers (Richardson et al., 2019). These prerequisites allow them to create visions and take and lead all those involved in a given school on the path to future education (Leana, 2011). Communication and knowledge sharing are the keys to successful technology integration in schools (Cox & McLeod, 2014; Ilomäki & Lakkala, 2018; Rismark & Solvberg, 2011; Sheppard & Brown, 2014).

On the other hand, the integration of technology in schools is regarded as a pivotal educational innovation (Backfisch et al., 2021), with the concept of OI positing that boundaryless knowledge flows are essential for organizations to create and profit from technology (Chesbrough, 2003, 2006; Chesbrough & Bogers, 2014). This necessitates the adoption of an appropriate mindset at all levels of the educational institution (Salampasis et al., 2015) and the implementation of novel leadership and management strategies as dynamic capabilities in technology integration (Bogers et al., 2019).

Our research demonstrates that supplementing the field's existing, predominantly qualitative research with supplementary methodological approaches can be advantageous. In addition to the method employed here, there are other potential avenues. For instance, assessing creativity using deep learning techniques and automated scoring (Sung et al., 2024) vanderli, measuring risk-taking using experiments (Smoleń et al., 2023), or capturing openness to experience with personalized mobile sensing approaches (Mayer & Bryan, 2024). A corresponding multi-method triangulation thus appears to be a logical approach to obtaining more differentiated insights in the future.

Besides, more research is needed to investigate other forms of KM in schools, e.g. knowledge storage, application, and creation, as our study focused on knowledge transfer practices only. Linking those internal KM strategies with the external search strategies of OI and schools' networking (Pietsch, Brown, et al., 2023; Pietsch, Cramer, et al., 2023; Richardson et al., 2019) as well as with the concept of knowledge absorptive capacity (ACAP; Da'as & Qadach, 2020; Lichtenthaler & Lichtenthaler, 2010) could offer relevant insights on how knowledge flows within and across schools are organized and beneficial for their innovation performance and technology integration. Even though we gained essential insights by finding the OIM as an antecedent of TL, intense research is required to specify conditions that support and foster digitalization-related TL leadership in schools.

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Appendix

Items and scales

Innovation outcome

Introduction: We would now like to know whether, and if so, to what extent process innovations, i.e. innovations or changes in the pedagogical work of the school that did not previously exist, have been introduced at your school within the last 12 months.

Measurement of innovativeness

Have any process innovations, i.e. innovations or noticeable changes that affect the pedagogical work of the school, been introduced at your school in the last 12 months?

Item measured on a binary scale (0 = no; 1 = yes).

Measurement of concrete innovations

(If yes) What were the most important innovations in this area in the last 12 months? Please name a maximum of three examples, ordered by importance!

Free-form fields

Justification of relevance of innovations

(always related to each of the mentioned innovations) Please explain in one sentence why this innovation was important for your school.

Free-form fields

Measurement of innovation radicalness

(always related to each of the mentioned innovations) Are these changes incremental (improving and/or supplementing and/or adapting what already exists) or radical (introducing something completely new) for your school?

Item measured on a ten-point scale (1 = incremental to 10 = radical).

This explanation was shown to the participants throughout the questionnaire block for all questions on innovation: "Process innovations include new or noticeably changed processes with regard to the pedagogical work of the school (e.g. teaching and instruction)."

Open innovation mindset

Base Question: Now we would like to know how you perceive yourself with regard to your own innovativeness, creativity and willingness to take risks. Please answer all the questions quickly and trust your spontaneous judgment. How much do you agree with the following statements?

- I see myself as someone who is original and comes up with new ideas. +
- I see myself as someone who is curious about many different things. +
- I exhibit creativity on the job when given the opportunity to. *
- I often have new and innovative ideas. *
- I come up with creative solutions to problems. *
- I think it's good when other people draw on my knowledge. #
- I think that different knowledge backgrounds may be helpful for the progress of a project. #
- I look for opportunities to exchange with persons having a different knowledge background. #
- My friends would say that I'm a risk taker.!
- I believe that failure is a necessary part of success.!
- I see a mistake as an opportunity to learn.!

+*openness,* *creativity, ! risk and failure tolerance (Engelsberger et al., 2022), *#positive attitude toward knowledge sharing and sourcing* (Antons et al., 2017)

All items were measured on a four-point scale (1 = strongly disagree 4 = strongly agree).

Knowledge Management (Knowledge Transfer Practices)

Base Question: In order for (new) knowledge to be sustainably integrated in a school, it is helpful to exchange information in a variety of ways. How did knowledge transfer take place within the school in the last 12 months?

- Information technologies (internet, intranet, e-mail, etc.) were used in order to encourage information flows and improve communication among teachers.
- The school's objectives and goals were clearly communicated repeatedly to all teachers.
- There were frequent, well-distributed internal reports that informed teachers about the schools' developments.
- There were formal mechanisms that guaranteed best practices to be shared in the school (e.g., between subjects, grades, or departments).
- There were projects involving interdisciplinary teams or working groups to share knowledge.
- Self-organized groups existed at the school in which teachers could learn from each other and exchange knowledge, e.g., communities of practice.

All items were measured on a four-point scale (1 = strongly disagree 5 = strongly agree) (Donate & Sánchez de Pablo, 2015).

Transformational leadership

Base Question: Now we would like to know something about your leadership behavior. For this purpose, statements that describe you as a leader are listed below. Please answer all questions quickly and trust your spontaneous judgment. How do you assess yourself in your current leadership role?

- I talk optimistically about the future.
- I seek different perspectives when solving problems.
- I talk with teachers about their most important values and beliefs.
- I help my schools' teachers to develop their strengths.

All items were measured on a four-point scale (1 = very rarely or never to 4 = very often) (MLQ; Bass & Avolio, 1995).