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ORIGINAL RESEARCH

# Open Innovation in Schools: A New Imperative for Organising Innovation in Education?

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**Abstract**
Schools are considered knowledge-creating organisations that find it difficult to develop and implement innovations on their own. Knowledge mobilisation is seen as the key to overcoming this problem. In particular, the use of external sources of knowledge is regarded as an important lever for change. However, there is a lack of concepts and empirical studies in educational research on the extent to which external knowledge is used for innovation in schools. Based on a sample of N = 411 schools, this article explores whether the concept of open innovation can be used in the context of education. Originating from the field of innovation research, open innovation regimes are seen as imperative if organisations are to create and benefit from technology. Multinomial logistic regression analyses show that mobilising external knowledge significantly increases the likelihood of implementing innovations in schools. A machine-learning approach reveals that it is necessary to tailor open innovation regimes to the specific conditions of any given school. In particular, with regard to the use of new technologies and innovations in the field of digitalisation, open innovation can be a lever for change.

**Keywords** Closed innovation · Innovation performance · Knowledge creation · Knowledge mobilisation · Open innovation · Schools

## 1 Introduction

In the face of current crises and to keep up with social and technological developments, schools are now, more than ever, required to implement innovations, some of which are long overdue (Brown & Luzmore, 2021; Schwabsky et al., 2020; Serdyukov, 2017; Tan et al., 2021). Innovations can lead to changes in school structure and functioning

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(Damanpour, 1988), are closely linked with experimentation and finding new approaches and ideas for educating children (Lubienski & Perry, 2019) and are ultimately enacted at the classroom level (Vincent-Lancrin et al., 2019). However, although innovation is seen as important for school effectiveness and countries around the world invest a lot of money in it, there are only a few empirical studies on innovation in education. Furthermore, the findings from this scant evidence base are inconclusive (Schwabsky et al., 2020; Serdyukov, 2017; Zimmer et al., 2017).

Due to the lack of adequate measurement models, little is known about what concrete innovations schools implement (Vincent-Lancrin et al., 2014, 2019). Accordingly, Serdyukov (2017), looking at one of the largest studies on this topic to date (Vincent-Lancrin et al., 2014), concludes that the list of innovations selected and reported in it is disappointingly unimpressive. In addition, little is known about which conditions in schools are conducive to successful innovation (Schwabsky et al., 2020), and there are too few empirical studies that examine (strategic) innovation and related knowledge management in schools (Cheng, 2021): that is, practices by which schools incorporate and coordinate the generation, dissemination and application of knowledge for innovating teaching and learning (Cordeiro et al., 2022).

Outside of educational research, in organisational and innovation research, however, the concept of open innovation has been considered imperative for organising innovation (Bogers et al., 2019) and especially *for creating and profiting from technology* (Chesbrough, 2003a). Open innovation theory suggests that organisations can and should use both external and internal knowledge to drive their innovation efforts and is seen as a lever to improve innovation performance (Bigliardi et al., 2020; Bogers et al., 2019; Chesbrough, 2003a). In particular, when the organisation of innovation processes is tailored to the specific needs of an organisation (Chesbrough, 2003a, 2012). Although, the concept of open innovation is used in the context of public administration (De Connick et al., 2021; Kankanhalli et al., 2017), it has hardly, to date, been applied in educational research and practice (Pietsch et al., 2023a).

A principal reason for this lack of application is that research on innovation in education itself is, on the one hand, still in its infancy (Vincent-Lacarin et al., 2014). Allied to this nascent state of the art, is that such research is also rarely linked to other, more mainstream research, on innovation (Halász, 2018). At the same time, however, the definition of innovation in education is more or less similar to that of other organisations (Schwabsky et al., 2020); and it has long been assumed in educational research that schools improve and change when they succeed in using newly created and acquired knowledge as a basis for changes to the beliefs, understanding and actions of all those involved in a school (Frost, 2012; Hanson, 2001). Nevertheless, introducing innovation in schools is considered a complex undertaking that requires a broad mobilisation of knowledge (Greany, 2018), as well as the active involvement and support of all stakeholders, from policymakers to learners (Serdyukov, 2017). Consequently, sourcing and sharing knowledge within schools as well as with outside people, communities and/or organisations is therefore seen as particularly important, especially for the implementation of sustainable innovation (Prenger et al., 2022).

Against this background, our article examines whether the concept of *open innovation* is transferable to educational research and whether and to what extent, open innovation regimes can lead to innovation outcomes in schools. More specifically, we examine whether and the extent to which the use of internal and external education-related knowledge is associated with different innovations in schools. For this purpose, we use a random sample of schools ($N=411$) from Germany and estimate latent multinomial logistic

regression models as well as apply a machine-learning approach. Herein, our study aims to fill the mentioned research gap by addressing the following research questions:

(RQ1) Do schools incorporate external knowledge for internal innovation?
(RQ2) Does externally mobilised knowledge (open innovation) increase the likelihood of innovations being introduced in schools compared to knowledge mobilisation within schools (closed innovation)?
(RQ3) Do closed and open innovation mechanisms interact with school-specific innovation conditions and contexts?

## 2 Innovation in Schools

Innovation in education is crucial for promoting improvements and sustainable development in schools (Nguyen et al., 2021). However, innovation is a multifaceted term that might attract a wide range of meaning and implications (Nicholls, 2018). In general, however, innovation can be described as the intentional emergence and implementation of new ideas, processes and solutions that imply both purposefulness and novelty (Damanpour, 1988, 1991; Rogers, 1995). In the context of education, innovation (as an outcome) is considered a subset of public sector innovation (OECD, 2009) and defined as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD & Eurostat, 2018, p. 60; see also Vincent-Lancrin et al., 2014, 2019).

According to Goldenbaum (2012, p. 81), innovations in the school context can be characterized more precisely as the following: "Innovations (…) tend to be relatively new, targeted, intentional, and planned measures that bring about changes or improvements in the school education system (macro-level), in the individual school (meso-level) and/ or in the classroom or social interactions (micro-level)". In short, this mean: Innovations in the context of schooling can be implemented at different levels of an education system and always involve at least the following three aspects: 1. they are fundamental in nature; 2. they are intentional and planned; and 3. there is an intention to improve or change (Nicholls, 2018).

In contrary to the business sector, innovation in the public service sector and thus in schools, is rarely driven by the pursuit of financial growth. The motivation to innovate arises from different sources that are, in most parts, connected with cultural, societal, or political changes and transitions (Goldenbaum, 2012): with main drivers of innovation in schools often being local competition between institutions and the regressive effects of large-scale, standardized reform strategies (Sahlberg, 2016). In addition, there are other external driving forces requiring schools or whole education systems to innovate, i.e., disruptive changes of educational environments like the COVID-19 pandemic (Pietsch et al., ), natural catastrophes and disasters (Brown & Luzmore, 2021), or man-made wars (and their consequences) (Kruszewska & Lavrenova, 2022).

However, as Tyack and Tobin's (1994) findings demonstrate, implementing innovation in schools is difficult because such institutions have a grammar of schooling in relation to long-standing structures (e.g. subject-based teaching, age-based classes, fixed timetables) that influence many aspects of teaching and absorbs innovative efforts. As research shows, the reasons for this are many. For instance, the structural characteristics of schools are limiting, with schools serving multiple constituents, making changes hard to plan and predict.

Further, schools are responsible for passing down civic and cultural knowledge and thus have a certain obligation to preserve the past (Brown & Luzmore, 2021; (Pietsch et al., 2023a, 2023b); Tye, 2000). Accordingly, even after innovations are introduced, changes in schools often regress after a while, with stakeholders and organisations returning to former behaviors and structures (Hopkins, 2013). As a result, schools tend towards the maintenance of stability by adopting incremental changes (Cuban, 2020), making it difficult for them to either innovate bottom-up, on their own, or integrate more radical top-down innovations (Elmore, 1996; OECD, 2015). Thus, successful innovation in schools requires a continuous and complex mobilisation of knowledge (Greany, 2018; Prenger et al., 2022) and the integration of this knowledge into existing organisational structures and routines (Da'as et al., 2020; Tappel et al., 2023).

## 3 Closed and Open Innovation

As school autonomy has increased worldwide (Hanushek et al., 2013; Hargreaves & Shirley, 2012), schools are increasingly expected to become innovative and effective as, according to the underlying assumptions of this approach, they were freed from bureaucracy whilst also being incentivised to compete with other schools for the best ideas and outcomes (Greany & Waterhouse, 2016; Preston et al., 2012). As a result, decision-making power has been increasingly shifted to schools, with an emphasis placed on teaching and learning, and a new focus established on school capacity building (Honig & Rainey, 2012). A key assumption here is that schools are knowledge creating organisations (Hargreaves, 1999) and so should (be expected to) develop innovative professional practices and processes internally (McCharen et al., 2011). As a consequence, as Hargreaves (1999, p. 125) argues, "schools which create professional knowledge are likely to display characteristics similar to those of high-technology firms that are demonstrably successful in knowledge creation in response to the dual demand for higher R&D [Research and Development] productivity and shorter development lead times."

Outside of educational research, Chesbrough (2003b) refers to such an innovation paradigm as closed innovation and argues that innovation processes in organisations that follow such an approach tend to be inward-oriented and strictly focused on progress and success. In this regard, the closed innovation model assumes that all knowledge providing the basis for innovation and change both can be and is produced internally by an organisation (Marques, 2014). Consequently, in this view, successful innovation requires control (Chesbrough, 2003b) and can only develop within organisations in a linear way, with scant regard for external expertise; subsequently leaving a majority of ideas unexploited (Chesbrough, 2012). Simultaneously, however, research indicates that such an approach to innovation is unable to cope with fast-changing and globally connected environments, meaning that closed and linear innovation models alone cannot be successful in the long run (Bigliardi et al., 2020). This argument also applies to schools, which often lack the capability and/or resources to change and innovate on their own (Bryck, 2010; Slavin, 2005).

Conversely, open innovation is seen as a key driver that helps organisations to overcome such constraints and to innovate in a dynamically evolving environment despite their own limited resources (Chesbrough, 2003a). The paradigm of open innovation is defined as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model" (Chesbrough & Bogers, 2014, p. 17). This paradigm

highlights the importance of open and cooperative research strategies which target both in and outflows of knowledge to accelerate internal innovation. According to the open innovation paradigm, different ways of inventing new ideas and technologies exist. Either they result from internal knowledge and need external paths to market, or they develop through external knowledge using internal paths to become successful (Chesbrough, 2006). Organisations must be open to external inputs, ideas, and contributors and allow internal knowledge to go beyond organisational boundaries to realise their full potential (Chesbrough, 2012). Inbound open innovation (integrating external knowledge) is the first level of open innovation, which enriches internal knowledge by integrating knowledge from external sources due to collaboration. This phase requires opening up processes and allowing innovation to develop beyond organisational boundaries. The second step is outbound open innovation (disseminating internal knowledge) involving the transfer of internal knowledge outside the organization and offering excellent chances for exchange and cooperation with other organizations. Further, it supports the main idea of open innovation that new ideas and expert knowledge do not emerge within closed organisational structures. The third and last phase is the coupled process (combining inbound and outbound mechanisms) which links inbound and outbound open innovation to develop shared values, strategic alliances, and networks between organizations (Gassmann et al., 2010; Pietsch et al., 2023a).

At the same time, however, both theory and empirical evidence indicate that for open innovation to be effective and achieve innovation outcomes, open innovation mechanisms must be fully aligned with an organisation's business model (Chesbrough, 2003a, 2012; West & Bogers, 2014). In other words, aligned with the description of an organisation and how it functions to achieve its goals (Massa et al, 2017): particularly in relation to: (i) configuration of knowledge co-creation within an organsisation; (ii) the permeability of knowledge flows across and within organisational boundaries; and (iii) the degree of collaboration with external knowledge providers (Ramírez-Montoya et al., 2022; Saebi & Foss, 2015). Furthermore, any such alignment will also vary with an organisation's internal and external contextual characteristics (Huizingh, 2011).

## 4 Methods

### 4.1 Study Context

Against this background, our study focusses on the differential effects of closed and open innovation in schools on various innovation outcomes. The context of this study is Germany, a nation comprising 16 federal states that are fully responsible for their individual school system. Despite these differences, students across all 16 states attend primary schools from the age of 6 to at least 10 years. Subsequently, however, students, once reaching fifth grade (at age 11) progress into a highly-structured and differentiated secondary school system. Nonetehless the traditional division into three school types (*Hauptschule, Realschule* and *Gymnasium*) has been successively reformed in most federal states (*Länder*) and in many places various forms of comprehensive schools have also been introduced. Yet, at the same time, innovation across all schools implemented very slowly in Germany, however, especially in the area of digitalisation. For example, in 2018, just before the start of the COVID-19 pandemic, only about 3.2% of schools in Germany had equipped all teachers with mobile devices (for comparison, the EU average was 25.9%; Eickelmann et al., 2019).

### 4.2 Sample

The database of our study is drawn from the third wave of the *Leadership in German Schools* (LineS) study. Data was collected between August and November 2021 across Germany. The longitudinal study surveyed a random sample of school leaders that is representative of Germany in each of the measurement waves (Cramer et al., 2021; Dedering & Pietsch, 2023; Röhl et al., 2022). Besides recurrent topics that are surveyed in every wave, specific topics are also used to highlight a subject focus in every single wave. The emphasis of the 2021 survey was on (open) innovation in schools. The *forsa Institute for Social Research and Statistical Analysis*, a leading survey and polling company in Germany, collected the data as a field service provider. Participants were recruited via its omnibus and omninet panels: here, a random sample of around 1,000 people aged 14 and above is interviewed on a mixed-topic daily basis, with questions also asking on the current occupation. Thus, school leaders ($N=411$) can be identified on a random basis, leading to a nationally representative sample for general schools in Germany. Participants received personalised access to an online questionnaire, hosted also by forsa. Of these, $N=103$ school leaders already participated in the previous two waves, and an additional refreshment sample of $N=308$ (Watson & Lynn, 2021) was surveyed. In our analysis we use cross-sectional data from all these sub-samples since data on open innovation has only been collected in this wave so far.

Of our sample, $N=247$ (63.3%) of the school leaders surveyed were female and N = 163 (36.7%) male. The average age was 52.9 years, with a standard deviation of 6.9 years. Respondents had been working as school leaders for an average of 9.5 years at the time of the survey. $N=35$ (8.5%) of respondents work in private schools, $N=374$ (91.0%) work in public schools, while $N=2$ (0.5%) did not respond to this question. Of the schools they lead, 63 (15.3%) are located in a village, hamlet or rural area (population less than 3,000); 106 (25.8%) are located in a small town (population 3,000 to approximately 15,000); 141 (34.3%) are located in a small city (population 15,000 to approximately 100,000); 75 (18.2%) are located in a medium size city (population 100,000 to approximately 1 million); and 25 (6.1%) are located in a large city (population over 1 million). It should be noted that, for one school, contextual data were missing.

In order to be able to present the school form in an internationally comprehensible way, we report education levels according to the International Standard Classification of Education (ISCED; UNESCO Institute for Statistics, 2012). ISCED classifies education systems according to uniform criteria: ISCED 1 refers to "primary education" and covers the first to fourth school years in Germany; ISCED 2 refers to "lower secondary education" and covers the fifth to the tenth school years; while ISCED 3 refers to "higher secondary education" and covers the eleventh to thirteenth school years. Within our sample, therefore: 53.2% are primary, 38.8% are secondary, 8.0% are other schools, including 2.0% special needs schools. On average, 381 students were enrolled in the participants' schools, with a standard deviation of 316 and a 5 to 95th percentile range of 60 to 1,027 students.

### 4.3 Measures

The questionnaire we employed for the survey comprised 35 item blocks. In addition to the items and scales relevant to the study, these include, for example, standardized constructs on self-efficacy (Röhl et al., 2022), stress experience, ambidexterity (Dedering &

Pietsch, 2023; Pietsch et al., 2023a, 2023b), and career choice and turnover intentions of school leaders (Cramer et al., 2021). For this reason, we use only a selection of items and scales in our study. That is, those that are relevant to answering our research questions. To minimise common method bias (Podsakoff et al., 2012), measures were taken, both in the instrument's design and in data collection. For example, item wording and scale properties varied across scales, and both item blocks and individual items within blocks were rotated and scrambled randomly across individual surveys. We used the following variables as part of our study (also see "Appendix"):

*Innovations*, our dependent variable, were measured by adapting items from the European Community Innovation Survey (CIS; Behrens et al., 2017), which is based on the Organisation for Economic Co-operation and Development's (OECD/Eurostat, 2018) Oslo guidelines for collecting, reporting and using data on innovation. Accordingly, we treat innovation as something that is new for a school, but not necessarily new for the entire education sector. In a first step, school leaders were asked whether innovations in pedagogical work, i.e., teaching and instruction, had been introduced at their school in the past 12 months, using a binary-coded item (0 = no, were not introduced, 1 = yes, were introduced). Specifically the wording of this question was:

> 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?

If school leaders answered yes to this question, as a second step they were asked to indicate up to three of the most important innovations in the past 12 months, using free-form fields that were ranked by importance. Related to these statements, they then, in a third step, were required to justify, again in free-form fields, why they considered these innovations important and, as a fourth step, rate how radical these are for their school on a scale ranging from 1 (incremental innovations—improving and/or supplementing and/or adapting what already exists) to 10 (radical innovations—introducing something completely new).

According to the data provided by school leaders, 78.8 percent of schools introduced innovations affecting teaching and instruction in the past 12 months; 19.2 percent of schools, however, did not introduce innovations; with no data on innovations were provided by two percent of school leaders. These innovations were seen by school leaders as comparatively radical for their schools ($M = 6.31$, $SD = 2.73$). For our analyses, the open-ended responses of what school leaders perceived as the most important innovation for their school during the last 12 months were coded and grouped into the following five categories: (a) innovating digital teaching and learning (64%), i.e., increases in the (appropriate) use of digital media in classroom; (b) innovating traditional teaching and learning (10%), i.e., the development of new, creative task formats; (c) innovating digitalisation (4%), i.e. the introduction of digital devices and software; (d) innovating social interaction (7%), i.e., the introduction of school-based parental involvement, and (e) other innovations (15%), e.g. the introduction of vocational orientation. Exemplary answers are provided in Table 1.

*Open innovation* was measured following Laursen and Salter (2006) and thus refers to inbound open innovation. Hence, it considers the diversity of external knowledge sources for innovation, i.e. open innovation breadth, and the intensity of use of those sources, i.e. open innovation depth. To capture a schools' open innovation orientation, school leaders were asked where the external knowledge for innovations for teaching, that were introduced in the last 12 months in their schools, came from (base question: "Now we would like to know where the knowledge came from for pedagogical innovations, i.e. teaching and instruction, introduced at your school in the last 12 months."). In

**Table 1** Coding of open responses on innovation outcomes in schools

| Category | Exemplary answers |
|---|---|
| Digital teaching and learning | "Distance learning and increasing the use of digital media also in face-to-face teaching" |
| Traditional teaching and learning | "We are changing our teaching concept to 'Individual learning with a system'" |
| Digitalisation | "Introduction of digital boards, iPads for students" |
| Social interaction | "Use of the school's internal messenger Cat4School to promote communication among teachers and between teachers and parents with a focus on student learning" |
| Other innovations | "Sustainability education", "Democracy education", "Vocational orientation" |

total, there were eight different response options (item stem: "The knowledge we used for the innovations came from…"), (a) parents, guardians, (b) other schools, (c) authorities, state institutes, (d) universities and other scientific institutions, (e) independent school-improvement consultants, (f) commercial companies, (g) professional trainings and/or conventions, and (h) professional literature. All items were measured on a six-point scale ranging from "not at all" to "to an exceptionally high degree". Open innovation depth represents the mean of those items. The open innovation depth scale's internal consistency, reported as McDonald's omega (1999), was $\omega = 0.76$. These items were also used to determine open innovation breadth by first coding the "not at all" category as zero and the other five categories as one, and then summing the number of all external knowledge sources and dividing by eight. This index of open innovation breadth thus has a minimum of zero (no sources of external innovation used) and a maximum of one (all possible sources of external innovation used). The open innovation breadth scale's internal consistency was $\omega = 0.80$.

*Closed innovation* refers to the amount of internal knowledge a school used for generating, developing and implementing pedagogical innovations in teaching and instruction during the 12 recent months and was captured with one item. Accordingly, school leader respondents were asked to what degree the knowledge for pedagogical innovations at the school came from within the school itself or from the school's teachers (base question: "Now we would like to know where the knowledge came from for pedagogical innovations, i.e. teaching and instruction, introduced at your school in the last 12 months.", item: "The knowledge we used for the innovations came from the school itself/ the teachers of our school."). The item was measured on a six-point scale ranging from "not at all" to "to an exceptionally high degree".

As open innovation theory suggests that open innovation systems need to be aligned with an organisation's business model and tailored to the specific conditions and structural characteristics of an organisation (Chesbrough, 2003a, 2012), following Becker (2005), Bernerth et al. (2018) and Spector and Brannick (2011), we also included control variables in our model. These were: school size or type, for which there is evidence of a relationship with innovation and change in education (Haelermans & Blank, 2012; Luyten et al, 2014); as well as variables related to the innovation orientation within schools (that is, innovation conditions and school leadership). Specifically, our *innovation conditions* include scales on *innovation climate, teacher innovativeness* and *school leaders' innovation networking activities.* These constructs were surveyed by adapting

scales from Popa et al. (2017), OECD (2019) as well as from Slavec Gomezel and Rangus (2019). Further detail on each is provided below.

The first of these innovation conditions, *innovation climate* ($\omega = 0.80$) comprised three items measured on a five-point scale ranging from "never" to "very often". An example item is: "Our school provides time and resources for teachers to generate, share/exchange, and experiment with innovative ideas/solutions". *Teacher innovativeness* ($\omega = 0.88$) comprised four items that could be rated on a four-point scale, ranging from "totally disagree" to "totally agree". (example item: "Most teachers in this school strive to develop new ideas for teaching and learning"). *School leaders' innovation networking activities*, were measured by asking school leaders how many hours per week on average they did spent in the last 12 months maintaining existing external contacts (e.g., face-to-face, e-mail, telephone, video conference) with people with whom they discuss strategic school matters (e.g., finance, school improvement, innovations). This was an open-ended question, so school leaders could enter numbers ranging from zero to 99 h per week.

*School leadership* was measured following Pietsch et al. (2019) and thus intending to capture leadership for learning, a blend of "instructional leadership, transformational leadership, and shared leadership" (Hallinger, 2011, p. 126). All leadership items were measured on a four-point scale ranging from "very rarely or never" to "very often". *Instructional leadership* ($\omega = 0.75$) was measured using two items from the Programme for International Student Assessment (PISA, OECD, 2014) (example item: "I ensure that teachers work according to the school's educational goals"). *Transformational leadership* ($\omega = 0.77$) was captured with four items from the Multifactor Leadership Questionnaire (MLQ, Bass et al., 1995), indicating idealized influence, inspirational motivation, intellectual stimulation, and individualized consideration (example item: "I seek different perspectives when solving problems"). *Shared leadership* was measured with one item (for a discussion on single item measures, see: Allen et al., 2022) from the Teaching and Learning International Survey (TALIS; OECD, 2019) (example item:"I provide staff with opportunities to participate in school decision-making").

### 4.4 Analytical Strategy

As a first step in investigating the effects of open and closed innovation practices on different types of educational innovation in schools, we constructed latent multinomial logistic regression models in M*plus* 8.4 (Muthén & Muthén, 2017). The reference group comprised of schools where, according to the surveyed school leaders, no innovations in teaching and instruction had been introduced in the last 12 months. Prior to analysis we standardised all continuous predictor variables with a mean of 0 and a standard deviation of 1, so that a one-unit change in the standardised predictor is actually a standard deviation change in the original predictor variable. Accordingly, the relevance of these variables, even if originally measured on different metrics, can be directly compared.

We report unstandardised beta coefficients and odd-ratios (OR), that compare each innovation type group: innovating digital teaching and learning; innovating traditional teaching and learning; innovating digitalisation; innovating social interaction; and other innovations—to the reference group of schools without innovations with respect to the reported predictors. Here, an OR of 1 indicates no effect, whereas an OR above 1 represents a positive effect, and a value below 1 indicates a negative effect (Hosmer et al., 2013). For example, an OR of 2 for a predictor means that it doubles the odds that the innovation under study will be introduced compared to no innovation being introduced. With an OR of

0.5, the opposite is true: the predictor reduces the odds of introducing the innovation under study by half compared to introducing no innovation.

Starting from a base model (Model 1), which only includes traditional closed innovation practices as a predictor, we successively include further sets of predictors. Model 2 adds open innovation breadth and depth. Model 3 additionally introduces control variables relevant to innovation within the school, i.e. leadership, innovation climate, etc., and contextual characteristics of the schools. Due to the small number of cases of other schools, we modelled school type a dichotomous variable—not ISCED 1 versus ISCED 1 (coded 0/1)—in our analyses.

To investigate interactions between innovation mechanisms, school conditions and contexts for innovation, and thus answering our third research question, we applied a classification and regression tree (CART) procedure (Breiman et al., 1984) using *R*. This machine learning approach was utilized to predict the innovation type with the same predictors included in Model 3 of the logistic regression model. The *rpart* function with its default settings (Therneau & Atkinson, 2014) was chosen to implement the algorithm that divides data into subsets based on the predictive power of independent variables. Thus, in terms of prediction accuracy, CART is expected to outperform multinomial logistic regression due to its robustness for outliers and non-linear relations, for example interactions among independent variables. CART is also expected to perform similarly when the associations between study variables are not complex. Another advantage of CART is that it conveniently handles missing data given that any observation with a non-missing value for the dependent variable and at least one predictor is not discarded. Hence, a successful CART implementation can serve as a sensitivity analysis and can reveal additional predictive information.

As the amount of missing data was low (2.1%), we used a full information maximum likelihood (FIML) procedure for handling missing data. Since the data for our study were collected from a single instrument, we also tested for the possibility of a common method bias using Harman's single-factor test (Harman, 1960). This test investigates whether a single factor or a general factor emerges to explain the majority of the covariance in the independent and dependent variables of an empirical study. Accordingly, we loaded all items in our study in an un-rotated exploratory factor analysis to see whether a single factor emerges or whether a general factor accounts for much of the covariance between the measured variables. This analysis evidenced that 18.6 percent of the covariance between the items under study could be explained by a single factor, far below the cut-off value of 50 percent (Lance et al., 2010), indicating a low likelihood of common method bias.

## 5 Results

### 5.1 Descriptive Statistics, Correlations and Univariate Analyses

Table 2 presents the means (*M*), standard deviations (*SD*) and correlations of our within-school study variables. Regarding RQ1, it appears that the schools in our sample for instructional innovation derive much more knowledge from closed innovation ($M = 4.45$) than from open innovation ($M = 2.39$) processes ($W(1) = 992.587$, $p < 0.001$). Results further show that school leaders' innovation network closeness is not statistically significantly correlated with any of the other model variables and that significant correlations with

**Table 2** Means, standard deviations and correlations of independent within-school variables

| | Variable | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Closed innovation | 4.45 | 1.17 | 1 | | | | | | | | |
| 2 | Open innovation depth | 2.39 | 0.67 | **.11** | 1 | | | | | | | |
| 3 | Open innovation breadth | 0.64 | 0.25 | .08 | **.84** | 1 | | | | | | |
| 4 | Innovation climate | 3.42 | 0.67 | **.18** | **.14** | **.14** | 1 | | | | | |
| 5 | Teacher innovativeness | 3.12 | 0.49 | **.35** | **.14** | **.14** | **.30** | 1 | | | | |
| 6 | Innovation networking | 6.29 | 5.69 | -.03 | .00 | .06 | .08 | -.06 | 1 | | | |
| 7 | Transformational leadership | 3.22 | 0.44 | **.16** | .09 | **.18** | .09 | **.27** | .03 | 1 | | |
| 8 | Instructional leadership | 3.37 | 0.46 | **.10** | .05 | **.12** | **.30** | **.27** | .03 | **.41** | 1 | |
| 9 | Shared leadership | 3.56 | 0.55 | **.12** | .08 | **.17** | **.17** | **.20** | .01 | **.31** | **.23** | 1 |

All bold correlations statistically significant at least at $p < .05$

all other model variables can be demonstrated for teachers' innovativeness, i.e. teachers' receptivity, openness and willingness to adopt change (Buske, 2018; Fullan, 2015).

According to the school leaders surveyed, the external knowledge for internal innovations in schools came primarily from professional trainings and conferences ($M = 3.50$), followed by knowledge flowing in from other schools ($M = 2.97$) and knowledge stemming from relevant professional literature ($M = 2.64$). On the other hand, little external knowledge for internal innovation came from government agencies ($M = 2.29$), universities ($M = 2.09$), and parents ($M = 2.09$). The knowledge of commercial companies ($M = 1.79$) and independent school consultants ($M = 1.66$) was almost not used at all to introduce pedagogical innovations in schools.

### 5.2 Multinomial Logistic Regressions

To answer RQ2, we investigated the impact of closed innovation practices in schools on innovation outcomes by applying multinomial logistic regressions, with 'no innovation' in teaching and instruction during the last 12 months being the reference (see Tables 3, 4, 5). Results of model 1 indicate that closed innovation practices in schools, hence, using internal available knowledge for pedagogical changes, is positively associated with both digital (OR = 2.042, $p < 0.001$) and traditional teaching and learning (OR = 1.719, $p < 0.05$) as well as with innovating digitalisation (OR = 2.340, $p < 0.05$), innovating social interactions (OR = 2.558, $p < 0.05$), and other relevant innovations, such as the introduction of vocational orientation or strengthening social work in schools (OR = 1.874, $p < 0.001$). Thus, if schools take advantage of teachers' internal knowledge, this increases the odds that such innovations will be introduced by about 100 percent, i.e., doubling the probability that such an event will occur.

Subsequently, we added open innovation measures to our analysis. Model 2 demonstrates the mixed effects of open innovation in schools. First, positive effects of closed innovation processes for innovations in schools can still be observed, even if open innovation processes are considered in the model. Second, we see that the effects of incorporating external knowledge for innovation in schools, i.e., innovation depth, are disproportionately larger with regards to innovations in digital teaching and learning, since we can observe significant correlations of open innovation depth with innovations in digital (OR = 4.568, $p < 0.001$) as well as in traditional teaching and learning (OR = 8.603 $p < 0.001$) in schools.

**Table 3** Regression coefficients, odd ratios and *p* values for the predictors of innovation in teaching and learning

| | Innovating digital teaching and learning (N = 208) | | | | | | | | | Innovating traditional teaching and learning (N = 31) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Model 1 | | | Model 2 | | | Model 3 | | | Model 1 | | | Model 2 | | | Model 3 | | |
| | b | OR | *p* | b | OR | *p* | b | OR | *p* | b | OR | *p* | b | OR | *p* | b | OR | *p* |
| *Innovation type* | | | | | | | | | | | | | | | | | | |
| Closed innovation (CI) | 0.714 | 2.042 | .000 | 0.762 | 2.143 | .000 | 0.743 | 2.102 | .000 | 0.541 | 1.719 | 0.014 | 0.653 | 1.921 | .004 | 0.705 | 2.024 | .016 |
| Open innovation breadth (OI-B) | | | | -1.133 | 0.322 | .000 | -1.129 | 0.323 | .000 | | | | -1.957 | 0.141 | .000 | -1.890 | 0.151 | .000 |
| Open innovation depth (OI-D) | | | | 1.519 | 4.568 | .000 | 1.550 | 4.709 | .000 | | | | 2.152 | 8.603 | .000 | 2.112 | 8.261 | .000 |
| *Innovation conditions* | | | | | | | | | | | | | | | | | | |
| Innovation climate (IC) | | | | | | | 0.045 | 1.046 | .799 | | | | | | | 0.148 | 1.159 | .672 |
| Teacher innovativeness | | | | | | | 0.021 | 1.021 | .897 | | | | | | | -0.154 | 0.857 | .436 |
| Innovation networking (IN) | | | | | | | 0.056 | 1.058 | .707 | | | | | | | 0.092 | 1.096 | .570 |
| *Leadership* | | | | | | | | | | | | | | | | | | |
| Transformational leadership (TL) | | | | | | | 0.284 | 1.328 | .125 | | | | | | | 0.485 | 1.624 | .291 |
| Instructional leadership (IL) | | | | | | | 0.036 | 1.037 | .841 | | | | | | | 0.028 | 1.028 | .413 |
| Shared leadership (SL) | | | | | | | -0.438 | 0.645 | .007 | | | | | | | -0.402 | 0.669 | .265 |
| *Context* | | | | | | | | | | | | | | | | | | |
| School type, ISCED 1[a] | | | | | | | -1.273 | 0.280 | .003 | | | | | | | -1.541 | 0.214 | .068 |
| School size | | | | | | | -0.086 | 0.918 | .720 | | | | | | | -0.567 | 0.192 | .229 |
| Rurality-urbanity | | | | | | | -0.004 | 0.996 | .976 | | | | | | | 0.053 | 0.216 | .272 |

[a]Reference category: not ISCED 1

**Table 4** Regression coefficients, odd ratios and p-values for the predictors of innovation in social interaction and digitalisation

| | Innovating Digitalisation (N = 12) | | | | | | | | | Innovating Social Interaction (N = 23) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Model 1 | | | Model 2 | | | Model 3 | | | Model 1 | | | Model 2 | | | Model 3 | | |
| | b | OR | p | b | OR | p | b | OR | p | b | OR | p | b | OR | p | b | OR | p |
| *Innovation type* | | | | | | | | | | | | | | | | | | |
| Closed innovation | 0.850 | 2.340 | 0.032 | 0.946 | 2.575 | 0.015 | 0.923 | 2.518 | 0.063 | 0.939 | 2.558 | 0.004 | 0.989 | 2.753 | 0.004 | 0.833 | 2.301 | 0.018 |
| Open innovation breadth | | | | −1.852 | 0.157 | 0.001 | −1.891 | 0.151 | 0.003 | | | | -0.934 | 0.392 | 0.049 | -0.886 | 0.412 | 0.064 |
| Open innovation depth | | | | 2.451 | 11.597 | 0.000 | 2.486 | 12.009 | 0.000 | | | | 1.457 | 4.283 | 0.003 | 1.426 | 4.160 | 0.003 |
| *Innovation conditions* | | | | | | | | | | | | | | | | | | |
| Innovation climate | | | | | | | −0.172 | 0.842 | 0.664 | | | | | | | 0.561 | 1.586 | 0.142 |
| Teacher innovativeness | | | | | | | 0.124 | 1.132 | 0.776 | | | | | | | 0.213 | 1.237 | 0.451 |
| Innovation networking | | | | | | | −0.574 | 0.563 | 0.204 | | | | | | | −0.088 | 0.916 | 0.776 |
| *Leadership* | | | | | | | | | | | | | | | | | | |
| Transformational leadership | | | | | | | 0.247 | 1.280 | 0.451 | | | | | | | −0.044 | 0.957 | 0.871 |
| Instructional leadership | | | | | | | 0.714 | 2.042 | 0.027 | | | | | | | 0.246 | 1.279 | 0.374 |
| Shared leadership | | | | | | | −0.441 | 0.643 | 0.209 | | | | | | | −0.136 | 0.873 | 0.668 |
| *Context* | | | | | | | | | | | | | | | | | | |
| School type, ISCED 1[a] | | | | | | | 0.268 | 1.308 | 0.799 | | | | | | | −1.555 | 0.211 | 0.032 |
| School size | | | | | | | 0.704 | 2.023 | 0.103 | | | | | | | −0.094 | 0.911 | 0.780 |
| Rurality–urbanity | | | | | | | −0.515 | 0.598 | 0.188 | | | | | | | 0.321 | 0.725 | 0.183 |

[a]Reference Category: not ISCED 1

**Table 5** Regression coefficients, odd ratios and p-values for the predictors of other innovation

| | Other innovations (N = 50) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Model 1 | | | Model 2 | | | Model 3 | | |
| | b | OR | p | b | OR | p | b | OR | p |
| *Innovation type* | | | | | | | | | |
| Closed innovation | 0.628 | 1.874 | 0.000 | 0.691 | 1.996 | 0.000 | 0.702 | 2.018 | 0.000 |
| Open innovation breadth | | | | −1.367 | 0.255 | 0.000 | −1.310 | 0.270 | 0.000 |
| Open innovation depth | | | | 1.649 | 5.201 | 0.000 | 1.610 | 5.003 | 0.000 |
| *Innovation conditions* | | | | | | | | | |
| Innovation climate | | | | | | | 0.655 | 1.925 | 0.006 |
| Teacher innovativeness | | | | | | | −0.240 | 0.786 | 0.252 |
| Innovation networking | | | | | | | 0.164 | 1.179 | 0.383 |
| *Leadership* | | | | | | | | | |
| Transformational leadership | | | | | | | 0.091 | 1.095 | 0.725 |
| Instructional leadership | | | | | | | −0.010 | 0.990 | 0.963 |
| Shared leadership | | | | | | | −0.503 | 0.605 | 0.025 |
| *Context* | | | | | | | | | |
| School type, ISCED 1[a] | | | | | | | −1.243 | 0.289 | 0.023 |
| School size | | | | | | | −0.204 | 0.816 | 0.490 |
| Rurality–urbanity | | | | | | | −0.068 | 0.934 | 0.722 |

[a]Reference category: not ISCED 1

Thus, when schools use a lot of external knowledge to innovate internally, the likelihood of introducing such innovations increases by five to eight times. We find an even stronger effect of open innovation depth for the digitalisation of schools (OR = 11.597, $p < 0.001$). However, the diversity of knowledge sources, i.e. open innovation breadth, has a negative effect on all reported innovations (all $p < 0.05$), with the exception of the social interaction innovation ($p > 0.05$). This is particularly noticeable with regard to innovations in traditional teaching and learning, such as the introduction of individualised learning or peer teaching within the classroom. Here, open innovation breadth is associated with an OR of 0.141 ($p < 0.001$), meaning that a school is more than 85 percent less likely to innovate in traditional teaching and learning if it draws on as many external sources of knowledge as possible.

In the final Model 3, in addition to closed and open innovation mechanisms, we also consider within-school innovation characteristics as well as school contextual conditions as control variables. This does not fundamentally change the relationship between innovation in schools and closed and open innovation mechanisms. However, two things stand out: first, controlling for covariates in the model, we no longer find both a significant effect for the influence of closed innovation mechanisms on digital innovations and an effect of open innovation breadth on the innovation of social interactions in schools (both effects $p > 0.05$). In general, therefore, model 3 also shows that the intensity of knowledge inflow in schools, i.e. open innovation depth, has a far greater effect on teaching and learning related innovations in schools than closed innovation processes. With regard to digitalisation in schools and innovations in the area of social interaction, it is even exclusively open innovation that plays a demonstrable role in whether or not corresponding innovations are subsequently introduced at schools. But here, too, it is evident that it is not the diversity,

i.e. open innovation breadth, but the quantity of knowledge, i.e. innovation depth, that has a positive influence, even when we control for school innovations and contextual features.

### 5.3 Classification and Regression Tree Analysis (CART)

To answer RQ3, we further examined interactions between our predictors and their joint effects on innovation in schools. As even "valid controls are possibly endogenous and therefore represent a combination of several different causal mechanisms" (Hünermund & Louw, 2020, p. 1) we investigated potential interactions of predictor variables by applying a machine learning approach in a final step, called CART. Unlike logistic regression, this approach does not develop a prediction equation, but explores the data set by partitioning the data along the predictor axes into subsets with homogeneous values of the dependent variable, allowing for multiple interactions between the predictor variables (Krzywinski & Altman, 2017).

Multinomial CART results indicate that eight out of 12 predictors have importance to predict the type of innovation with the following weights: open innovation depth 26%, closed innovation 22%, school size 19%, open innovation breadth 18%, ISCED 6%, teacher innovativeness 4%, transformational leadership 2% and innovation climate 2%. CART results are depicted in Fig. 1 using the *R* package *rattle* (Williams, 2011), so illustrating the interactions among variables to predict innovation type as frequencies reported in each node. For example, the first node, before partitioning, reports 208 as the frequency for innovating digital teaching and learning (type-1); 31 for innovating traditional teaching and learning (type-2); 12 for innovating digitalisation (type-3); 23 for innovating social interaction (type-4); 50 for other innovations (type-5), and 87 for no innovation (type-6). The header in each node shows the highest frequency, for example 1 for the first node. Results show that open innovation is the strongest predictor for teaching-related innovations in schools. It is striking, however, that closed innovation is the decisive predictor when it

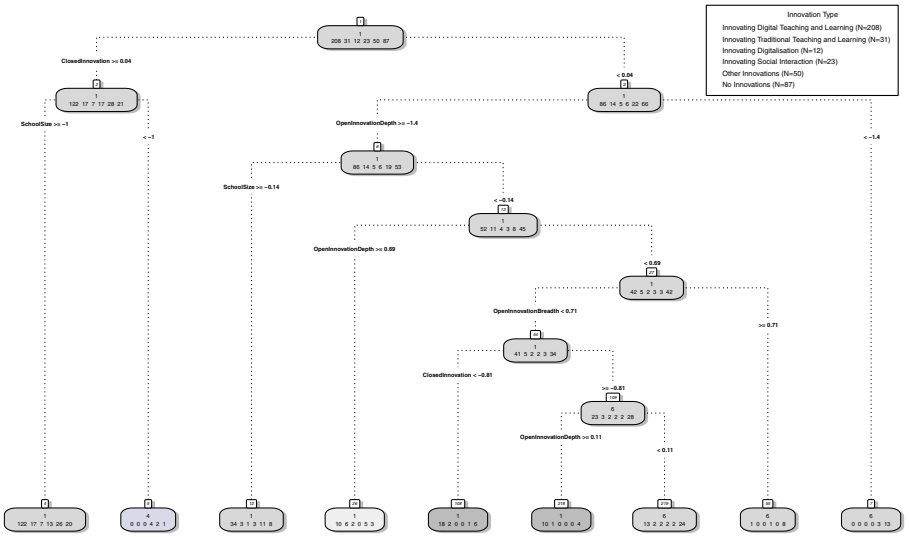


**Fig. 1** Classification and regression tree (CART) model for innovation in schools

comes to the implementation of innovations in schools in general since all other predictors depend on closed innovation or interact with the closed innovation mechanisms of schools. It is also striking that an above-average use of closed innovation is used in schools that are not particularly small (less than one standard deviation below the mean) and that open innovation depth comes into play especially when closed innovation is below average.

To compare CART's predictive accuracy with the multinomial logistic regression model for our final analysis we employed 5000 resamples using the *caret* package (Kuhn, 2008). Here the median value of predictive accuracy was 0.50 for the multinomial regression and 0.57 for CART indicating a slightly better performance for the latter. Overall based on the CART results it can be argued that relations between the study variables are rather complex than linear and that the effectiveness of open innovation a) is key to innovation in schools, b) depends on closed innovation mechanisms and c) interacts with conditions of the respective school.

## 6 Discussion

The findings show that both closed and open innovation depth affect innovations in schools. Specifically, open innovation depth has a far greater effect on innovation in teaching and learning (traditional and digital) than effects of closed innovation. These findings are consistent with findings from general organisational and innovation research (Bogers et al., 2019; De Coninck et al., 2021). They also show that schools need stimuli to open up to externally inspired innovations and so overcome their traditionally strong self-recursiveness if they are to keep pace with social and technical developments. For instance, teacher professional development should be sensitive to questions, such as how teachers understand proposed innovation, how those can be enacted, and what fosters the adaption of external knowledge to the local conditions (Silver et al., 2019).

What is striking, however, is that open innovation depth is the only innovation mechanism having a significant effect on digitalisation in schools, when contextual factors are taken into account. This finding supports the notion that open innovation is particularly useful in enabling schools to benefit from new technologies (Chesbrough, 2003a): especially when existing staff are unlikely to have an understanding of, or experience relating to, such technologies. The finding that open innovation breadth has negative effects on all innovations also seems significant. This result is also consistent with the findings of other studies that find a curvilinear relationship between open innovation breadth and innovation performance (Laursen & Salter, 2006; Shi et al., 2019; Terjersen & Patel, 2017).

Accordingly, also in schools such a potential over-search (Shi et al., 2019) seems to make it difficult to identify and allocate resources to valuable sources of knowledge, which in turn might have a negative impact on innovation performance. In other words, too many parallel activities undertaken all at once may lead to a diffusion of forces instead of a concentration of activities, which is not conducive but even a hindrance to the innovations aimed at. There is thus a danger of a failure trap (Pietsch et al., 2023b), i.e., a parallelism or succession of ever new measures, which leads to no sustainable innovation. This parallelism also applies to teaching, when teachers constantly explore new teaching concepts and methods inspired by continuing professional development activities or other external sources, without following a specific strategy or didactic concept. In this respect, open innovation in pedagogical practice must not be misunderstood as an aimless

experimentation as a result of multiple external inspirations. Rather, the professional action of teachers in the classroom is tied to reasoned trade-offs between options.

Indeed, there is seemingly a particular risk of the emergence of failure traps in education systems because, when it comes to education, reforms regularly form part of the political discourse, and innovations (intended to solve perceived educational issues) are often introduced to schools from the outside. Depending on the regularity of this introduction, such policy-making could even prevent schools from using external knowledge in the sense of (self-motivated) proactive open innovation. In this respect, the role of education policy, such as with medicine, should perhaps not be to prescribe specific innovations per se, but to demand and promote open innovation (Jiao et al., 2022).

It is further striking that the open and closed innovation mechanisms are not dichotomous categories, but rather interwoven mechanisms. As depicted in Fig. 1, open innovation's effectiveness is present when the score for closed innovation is low. In line with Marques (2014), we therefore argue that both mechanisms are closely intertwined and that an interplay of closed and open innovation regimes is important when it comes to educational innovation and change. This finding also suggests that it is important for externally mobilised knowledge, i.e. open innovation depth, to be linked to the knowledge already available in the school in order for it to become effective. As a result, our study also contributes to the theoretical discussion in innovation research and in particular to the debate on how to organise innovation through distributed approaches. It is argued here that when organisations combine internal and external search strategies to access different resources for innovation, new challenges arise from the complementary management of these knowledge sources (Lakhani et al., 2013; Tushman et al., 2012). Our empirical analyses clearly demonstrate this, and suggest that the simultaneous pursuit of multiple types of organisational boundaries means that schools have to deal with complex, often internally conflicting innovation logics and their structural and procedural requirements. Our study is the first to show therefore that, even in schools, the ability to identify and acquire relevant external knowledge, and to link it to internal knowledge through transformation and exploitation, is significantly determined by the ability of a school and its actors to benefit from open innovation mechanisms. Thus, a school's absorptive capacity (Da'as & Qadach, 2020) is an important determinant of the effective use of external knowledge (Lichtenthaler & Lichtenthaler, 2009; Lowik et al, 2017). In the end, it is likely to be of particular relevance whether innovations at the level of the school as an organization also reach pedagogical practice through the actions of teachers in the classroom, about which little is yet known.

Finally, the effect of open innovation depth on innovations generally varies with other inner-school conditions as well as school contexts. This also corresponds to the assumptions and findings on open innovation research from other fields (Chesbrough, 2003a, 2006, 2012): The more closely open and closed innovation regimes are tailored to the conditions and needs of a school, the more likely they are to be effective. In this regard, it is striking that most of the contextual variables we examined have only a minor influence on the innovation outcome in schools, but that school size is a crucial characteristic in determining whether or not closed innovation mechanisms are sufficient for innovation in schools. Particularly in schools of above-average and below-average size, open innovation seems to act as an additional resource to closed innovation mechanisms and to mitigate possible resource constraints. This finding is also connectable to empirical findings outside of education research, which indicates a relationship between organisational size and organisational innovation (Aldieri & Vinci, 2019; Mote et al., 2016).

As in other studies, it can, finally, be seen that the relationships are not linear but complex, especially when it comes to technology and digitalisation (Lee & Xia, 2006). This

also underlines the need to prepare teachers for a future-proof profession in such a way that they deal appropriately with this complexity and uncertainty in the field of pedagogical action, so that they do not implement external knowledge into the school in a decontextualized way (Cramer et al., 2023). Methodologically, our study here demonstrates the potential of machine learning approaches for the study of non-linear and complex relationships in educational research (Hilbert et al., 2021. In particular, it highlights the value of such methods as a tool for testing and pruning theories, and as a catalyst for broadening the range of explanations that a theory can contain in organisational research in general (Leavitt et al., 2021), and in educational innovation and effectiveness research in particular (Hu et al., 2022).

## 7 Limitations

As far as we know, our study is one of the first to empirically examine Chesbroughs' (2003a) concept of open innovation in the school context. Although our investigation accordingly reveals many possibilities for further research, it also has several limitations. The first relates to it cross-sectional rather than time-series nature, and thus our ability (or lack thereof) to generalise results gathered from one point in time in Germany. Consequently, on the one hand, causality can only be inferred, but cannot be demonstrated. Related is that we cannot assess whether the reported effects are similar in other contexts. We were also unable to investigate how open and closed innovation processes emerge and develop and to what extent these two innovation paradigms interact with each other dynamically over time (Chiaroni et al., 2011). Further, our analyses are based on self-reports of school leaders, so neither misreporting nor perceptual distance (Tafvelin et al., 2017) between leaders and other organisational members, i.e. teachers, can be completely ruled out. Accordingly, there is also the possibility that micro-level innovations regarding individual teachers and classrooms were not perceived and reported. In measuring open innovation, we followed Laursen and Salter (2006). Accordingly, our list of potential knowledge sources is not exhaustive and could theoretically be expanded (or contracted) to include (or exclude) other options. Furthermore, following the model, we did not investigate whether there are individual knowledge sources that are particularly relevant, as we were interested in comparing our findings with those of studies that also followed Laursen and Salter (2006). Hence, future research should try to apply longitudinal designs, gather data at different levels of schools and across various contexts, and should investigate whether there are specific sources of knowledge that are particularly relevant to stimulating innovation in schools.

## 8 Conclusion, Implications and Future Research

Our findings provide first and preliminary evidence that the concept of open innovation can be applied in the context of education. It is obvious that schools are highly dependent on external knowledge if they want to keep up with social and technological developments. Using the knowledge available in the school, i.e. closed innovation, seems to be no longer enough. The extent to which external knowledge effectively influences internal innovation depends on the respective conditions of the individual school. In particular, the mobilisation of internal school knowledge is an important prerequisite for externally mobilised

knowledge to become effective. Especially when it comes to the use of new technologies and innovation in the field of digitalisation, open innovation can be a lever for change in schools.

Regarding policy and practice in education, this means that it is important to prepare schools and school staff (both in teacher education and while qualifying school leaders) to be open to appropriate knowledge flows, e.g. by strengthening open innovation mindsets (Bogers et al., 2019; Chesbrough, 2017; Engelsberger et al., 2022) and (individual) absorptive capacity (Aliasghar et al., 2019; Lichtenthaler & Lichtenthaler, 2009; Spithoven et al., 2010). As schools "are historically weak at knowledge sharing within and across schools" (Fullan, 2002, p. 409), it might also be necessary to address possible negative attitudes of teachers towards externally acquired knowledge in order to overcome possible "not-invented-here" barriers (Antons & Piller, 2015; West & Bogers, 2014). Given that managing broad and heterogeneous sources of knowledge requires a substantial share of management time and attention (Aliasghar et al., 2020), and that an accompanying over-search can ultimately lead to negative effects in pedagogical innovation in schools (Pietsch et al., 2023a; Shi et al., 2019), it also seems necessary to enable school leaders to direct both individual and school capacities towards influential innovation opportunities. It is a desideratum to better understand how exactly innovations at the level of the school as an organization ultimately show up in pedagogical practice in the classroom or in teacher action.

This is also followed by perspectives for further research: Given the generally very limited evidence on the influence of inbound open innovation on the development of process innovations (Aliasghar et al., 2020) and the fact that especially complicated process innovations, which were the subject of our study, can cause high transaction and opportunity costs for external knowledge mobilisation (Shi et al., 2019), it makes sense in principle to identify configurations for optimal knowledge flows within, into and between schools. Further, we currently know very little about teachers' and school leaders' mindsets and attitudes towards knowledge creation and sharing for innovation within and across schools (Berson et al., 2015) and nothing at all about this with regard to the concept of open innovation. Accordingly, on the one hand, it seems purposeful to investigate the applicability of these concepts to school and teaching. On the other hand, it might be promising to investigate their connection with the innovative capacity and innovation performance of schools in future research.

## Appendix: Items and Scales

### Innovation Outcome

Introduction: We would now like to know from you 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 at your school, have been introduced at your school in the last 12 months.

### Measurement of Innovativeness

Have 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 the each mentioned innovation) Please explain in one sentence why this innovation was important for your school.

- Free-form fields

### Measurement of Innovation Radicalness

(always related to each mentioned innovation) 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).

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

### Closed and Open Innovation Depth and Breadth

Base Question: Now we would like to know where the knowledge came from for pedagogical innovations introduced at your school in the last 12 months. The knowledge that we used for the innovations came…

…from the school itself/ the teachers of our school. +
…from parents and guardians.*
…from other schools.*
…from school authorities, other authorities or official institutions, e.g. state institutes.*
…from academic institutions, e.g. universities.*
…from freelance or independent school improvement consultants.*
…from commercial enterprises.*
…from professional trainings and/or conventions.*
…from professional literature.*
+ *closed innovation*, **open innovation.*

- All items were measured on a six-point scale (1 = not at all to 6 = to an exceptionally high degree).

### Innovation Climate

Base Question: How often are teachers offered the following opportunities at your school?

Our school provides time and resources for teachers to generate, share/exchange, and experiment with innovative ideas/solutions.

Our teachers frequently encounter nonroutine and challenging work that stimulates creativity.

Our teachers are recognized and rewarded for their creativity and innovative ideas.

- All items were measured on a five-point scale (1 = never 5 = very often).

### Collective Teacher Innovativeness

Base Question: Thinking about the teachers in your school, how strongly do you agree or disagree with the following statements?

Most teachers in my school strive to develop new ideas for teaching and learning.

Most teachers in my school are open to change.

Most teachers in my school search for new ways to solve problems.

Most teachers in my school provide practical support to each other for the application of new ideas.

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

### Innovation Network Closeness

In the last 12 months, how many hours per week on average did you spend maintaining existing contacts (e.g. in person on site, via email, by telephone, as a video conference) with people outside the school with whom you discussed school strategy matters (e.g. finances, school development, innovations)?

- Free-form field (option: 0 to 99)

### School Leadership for Learning

Base Question: Now we would like to know something about your leadership behaviour. For this purpose, statements that describe you as a leader are listed below. Please answer all questions quickly and trust your spontaneous judgement. 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 teachers in my school to develop their strengths.+

I provide opportunities for teachers to actively participate in school decisions.*

I ensure that teachers work according to the school's educational goals.#

When a teacher brings up a classroom problem, we solve the problem together.#

+*transformational leadership*, **shared leadership, #instructional leadership.*

- All items were measured on a four-point scale (1 = very rarely or never to 4 = very often).

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**Data Availability** The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors have not disclosed any competing interests.



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