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Linear and nonlinear relationships between instructional leadership and teacher professional learning through teacher self-efficacy as a mediator: a partial least squares analysis

Lei Mee Thien ¹✉ & Peng Liu²

Although the investigation of instructional leadership and teacher professional learning is well-documented in the literature, one overlooked question concerns the linear and nonlinear relationships between these two variables. This study aims to examine the linear and nonlinear relationships of principal instructional leadership on teacher professional learning through teacher self-efficacy as a mediator. This study has collected 335 teacher samples encompassing both primary and secondary school levels in Penang, Malaysia. The analysis of data utilised partial least-squares structural equation modelling. The findings indicated a significant positive linear relationship between instructional leadership and teacher-professional learning. Likewise, there exists a significant mediating effect of teacher self-efficacy between instructional leadership on teacher professional learning. There exists a significant nonlinear relationship between principal instructional leadership on teacher self-efficacy and teacher professional learning respectively. The structural model exhibits a significantly high level of predictive power for in-sample and out-of-sample. This study offers theoretical and methodological advancements in comprehending the complex relationships between instructional leadership and teacher outcomes. It proposes that forthcoming studies could adopt a combination of linear and non-linear relationships to achieve robust empirical findings.

¹School of Educational Studies, Universiti Sains Malaysia, Minden, Penang, Malaysia. ²Faculty of Education, University of Manitoba, Winnipeg, Manitoba, Canada. ✉email: thienleimee@usm.my

Introduction

Teacher professional learning is often characterised as the ongoing process of teachers' learning and growth, encompassing both formal professional learning activities (such as teacher research groups and mentoring relationships) and the informal learning that occurs within the context of their job. This dual approach, as highlighted by Hallinger and Kulo-phas (2020), underscores the significance of continuous learning for teachers. Acknowledging its pivotal role, teacher professional learning becomes a cornerstone in fostering student learning, as the effectiveness of teachers significantly influences students' learning outcomes (Chen, 2022).

There is a plethora of extant empirical studies that support that principal leadership and teacher attitudinal variables significantly contribute to the enhancement of teacher professional learning (Liu and Hallinger, 2018; Qian and Walker, 2013). The instructional leadership of principals emerges as a crucial factor affecting the teachers' professional learning, especially in the Asian region (Amzat et al., 2022; Bellibas et al., 2021; Hosseingholizadeh et al., 2020; Liu and Hallinger, 2018). The relationship between instructional leadership and teacher professional learning is primarily a subject of enquiry concerning whether the relationship is direct or indirect within a structural model at a single level (Bellibas et al., 2021; Hosseingholizadeh et al., 2020). Prior empirical studies commonly incorporate teacher attitudinal variables, including teacher self-efficacy and teacher trust, as mediators within structural models (Karacabey et al., 2022; Thien et al., 2023). These extensive quantitative investigations in this field have significantly enhanced and added novel insights to the literature on educational leadership and management. While acknowledging their merits, it can be argued that these empirical studies may have limitations in failing to consider the inherently complex and dynamic nature of the relationships between school leadership and teacher outcomes, given that schooling is intricately embedded within an open system (Ng, 2021). This becomes apparent in the inconsistencies found in previous studies on instructional leadership and teacher-professional learning (Thien and Yeap, 2023).

Most empirical findings indicate that instructional leadership is associated with a moderate and positive correlation with teacher professional learning responses, as evidenced by studies such as Karacabey et al. (2022) and Liu and Hallinger (2018). Nevertheless, there are instances in previous studies, such as Thien et al. (2023), where a nonsignificant relationship between instructional leadership and teacher-professional learning has been observed. These mixed findings imply that the relationship between these two variables may not be a simple linear relation. The potential nonlinear relationship suggests that how instructional leaders react and behave when they are supportive of teacher professional learning might be more heterogeneous than previously thought. Thus, the investigation of instructional leadership by principals and professional learning among teachers without a possible nonlinear relationship to affirm the robustness of a proposed research model remains debatable.

Missing the substantive opportunity to use advanced analytic methods such as non-linear analysis may limit the level of the analysis quality and restrict more insightful empirical findings (Guenther et al., 2023). The ignorance of nonlinear relationships between variables could engender relationships that are erroneously assumed (Ghasemy et al., 2021; Thien and Lee, 2022). Indeed, the literature lacks a comprehensive investigation of both linear relationships and a subsequent robustness check on the nonlinear relationship of instructional leadership, which could effectively elucidate the dynamics of teacher professional learning.

Moving beyond simply assessing whether the direct or linear relationship between instructional leadership on teacher

professional learning is mediated by teacher self-efficacy, this study delves into how these three variables are likely associated with each other in a nonlinear way. This study seeks to address the research questions as follows.

1. Is there any significant direct (linear) relationship between instructional leadership and teacher professional learning and teacher self-efficacy respectively?
2. Does teacher self-efficacy mediate the relationship between instructional leadership and teacher-professional learning?
3. Is there any significant nonlinear relationship between instructional leadership and teacher professional learning and teacher self-efficacy respectively?

This study contributes new empirical findings to the body of knowledge in educational leadership-teacher outcomes literature. Previous studies have mainly focused on the linear relationship between instructional leadership and teacher professional learning with teacher self-efficacy enacting as a mediator (Liu and Hallinger, 2018). This study enhances comprehension by exploring both linear and nonlinear relationships among these three variables.

Prior research has predominantly concentrated on the linear relationship between instructional leadership and teacher-professional learning, with teacher self-efficacy enacting as a mediator (Liu and Hallinger, 2018). In contrast, this study enhances comprehension by exploring both linear and nonlinear relationships among these three variables. Nonlinear relationships could generate a significant knowledge gap with linear relationships. The current study is timely as knowing the existence of nonlinear is critical because it may influence instructional leadership-teacher professional learning relationships.

Theoretical foundations and formulating hypotheses

Teacher professional learning. Professional learning, often characterised as an ongoing and dynamic progression (Liu and Hallinger, 2017), underscores the responsibility of schools in furnishing teachers with learning chances (Hairon and Tan, 2017). The concept of teacher-professional learning encompasses both formal and informal learning activities, involving collaborative efforts among teachers to attain educational objectives (Hallinger et al., 2019; Li et al., 2016). Many job-embedded activities, including professional development workshops, professional learning communities, and peer mentoring, are expected to enhance teacher professional learning (Vescio et al., 2008). At the school level, teacher professional learning plays a significant role in ensuring school effectiveness (Karacabey et al., 2022; Liu and Hallinger, 2021), thereby beneficial for teachers and students at the individual level. Students learning outcomes could be achieved through teacher-professional learning (Hattie, 2009). Professional learning opportunities, where teachers may exchange expertise in various subject areas and communicate about the barriers related to classroom instruction, satisfy teachers' professional learning needs (Alsaleh, 2020). Liebman et al. (2005) contended that several components of teacher professional learning, including the widely accepted belief about school values, reflective conservation, cooperation, and student-centred learning, are indispensable for improving school performance. Teacher professional learning contributes to school reform by enhancing teachers' expertise in specific content areas to cope with the changing world (Liu and Hallinger, 2021). In this study, teacher professional learning was conceptualised as "a product of both externally provided and job-embedded activities that increase teachers' knowledge and change their instructional practice in ways that support student learning" (Wei et al., 2009, as cited in Li et al., 2016).

Instructional leadership. Instructional leadership has evolved as a significant paradigm guiding empirical studies, policies, and practices in school leadership. It plays a pivotal role in fostering the advancement of teaching and learning (Bellibas et al., 2022; Li et al., 2023). Studies on instructional leadership have a history dating back to the 1980s, as noted by Hallinger and Bryant (2013). The concept of instructional leadership was renowned in North America and researchers started to direct their attention to instructional leadership outside North America in 2000 (Hallinger and Bryant, 2013).

Evolving from a conventional conceptualisation in terms of there being an authoritative principal to enhance teaching and learning in the classroom, to an instructional principle who incorporates shared and collaborative, and transformational theories of leadership (Salo et al., 2015) in influencing teaching through their formal administrative roles at school (Hallinger, 2011). Hallinger and Murphy's (1985) instructional leadership framework has been extensively applied in voluminous empirical studies. This framework has clarified the obligation of schools and stressed the importance of the school environment for student learning (Hallinger and Murphy, 1985).

Hallinger and Murphy's (1985) instructional leadership framework comprises three dimensions. First, defining the school mission, which refers to the principal's responsibility for articulating and communicating a vision for learning and building support for enacting the vision of the school. Second, managing the instructional programme, which refers to the school leaders' practices in developing, coordinating, and monitoring the quality of teaching and learning. The instructional leadership framework proposed by Hallinger and Murphy (1985) encompasses three dimensions. Firstly, there dimension of defining the school mission. This dimension refers to the principal's duty of clearly expressing and communicating a vision for learning, as well as garnering support for bringing that vision to fruition within the school. The second dimension is managing the instructional programme. This dimension refers to the level to which the practices of school leaders in fostering, coordinating, and overseeing the quality of teaching and learning. the third dimension is developing a positive school learning climate. This dimension denotes the responsibility of school leaders in fostering an environment within the school that encourages and aids both teachers and students in actively participating in the teaching and learning process. Previous studies have revealed that principals' instructional leadership is crucial for building school structures that facilitate teacher professional learning (Hallinger, 2005). More specifically, instructional leaders may enhance teaching quality by offering feedback for instructional activities and assessing students' needs (Torres Clark and Chrispeels, 2022).

Instructional leadership and teacher professional learning. The imperative role of principal instructional leadership in enhancing teacher professional learning is well-documented in the literature (Liu and Hallinger, 2017, 2018; Thien et al., 2023). A possible reason is instructional leadership is of vital importance in shaping a positive learning environment for teachers and promoting teachers' learning motivation (Hammad et al., 2021; Qian et al., 2017). Past empirical research has demonstrated that instructional leadership exerts a substantial and positive influence on teacher professional learning across various research contexts (Hammad et al., 2021; Karacabey et al., 2022; Liu and Hallinger, 2021).

For instance, Liu and Hallinger (2018) evidenced a substantial direct relationship between instructional leadership and teacher-professional learning ($\beta = 0.598$, $p < 0.001$). Meanwhile,

instructional leadership and teacher-professional learning, which influence teaching practices in the Turkish classroom, are essential components of school improvement initiatives (Bellibas et al., 2021). Similarly, Karacabey and his associates (2022) have confirmed that instructional leadership is positively related to Turkish teacher professional learning ($\beta = 0.313$, $p < 0.001$). These previous findings implied teacher professional learning could be improved when principals, who are instructional leaders, are involved in the learning activities. Instructional leadership could contribute to teacher professional learning by facilitating professional learning communities and teacher collaboration by building trust and shaping a positive collegial relationship in schools (Hammad et al., 2021; Ma and Marion, 2021; Zheng et al., 2019).

Apart from that, qualitative research indicates that principals' instructional leadership plays a crucial role in shaping a positive school environment, thereby fostering teacher professional development (Harris et al., 2017, 2019). Drawing insights from interviews with school administrators, Harris et al. (2017) argue that in Malaysia, principals enhance teachers' instructional practices through the facilitation of professional learning initiatives and the oversight of teaching qualities. In addition, a qualitative study conducted by Park and Ham (2016) affirmed the substantial role of principals' instructional leadership in nurturing collegial relationships and cultivating teacher collaboration. This, in turn, contributes to the enhancement of teacher professional learning. Thus, hypothesis 1 was formulated as follows.

H1: Instructional leadership has a linear and positive relationship with teacher professional learning.

Instructional leadership and teacher self-efficacy. Based on Bandura's (1997) social cognitive theory, instructional leaders have the capacity to enhance teacher self-efficacy via the provision of vicarious experiences (live modelling) and verbal persuasion (feedback and encouragement). Hence, instructional leadership could influence teachers' beliefs, classroom behaviours, and teaching practices (Blasé and Blasé, 2000). Alanoglu (2022) conducted a meta-analysis that affirmed a positive relationship between instructional leadership by principals and teacher self-efficacy. The earlier study by Ross and Gray (2006) believed that school leaders can promote students' learning performance through teachers' self-efficacy indirectly. Moreover, instructional leadership could foster teachers' motivation to attend professional learning activities where teachers may receive instructional assistance from school principals (Duyar et al., 2013). This could be because instructional leaders could improve teacher efficacy beliefs by enhancing the school environment, identifying schools' responsibilities, and operating educational programmes (Geijsel et al., 2009). Another possible reason is that instructional leadership could offer theoretical foundations for teacher self-efficacy from cognitive and social perspectives (Lee et al., 2011). Teacher cooperation, teachers' expectations for students, and teachers' administrative duties may impact the relationship between instructional leadership and teacher self-efficacy (Geijsel et al., 2009; Thoonen et al., 2011). Thus, hypothesis 2 was postulated.

H2: Instructional leadership has a linear and positive relationship with teacher self-efficacy.

Teacher self-efficacy and its role as mediator. Self-efficacy, a vital element within the social cognitive theory, encompasses individuals' attitudes toward tackling challenges (Bandura, 1997). It has the potential to influence people's thought patterns and behaviours, particularly impacting motivation. Those with elevated self-efficacy levels are more likely to exert effort in

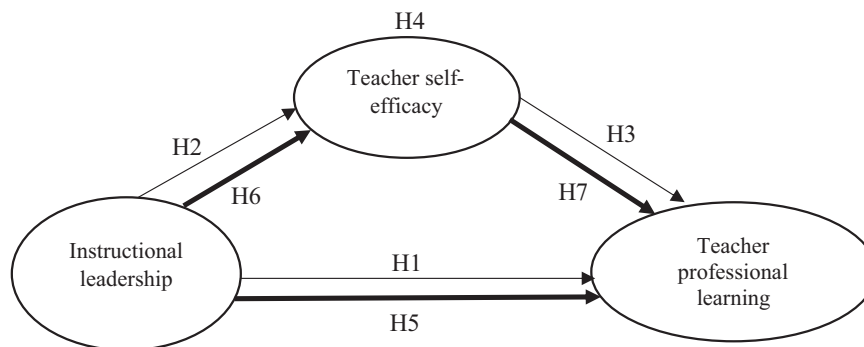


Fig. 1 Research model. Note: The black straight lines represent linear effects. The bold straight lines represent nonlinear effects.

successfully completing challenging tasks (Schwarzer and Hallum, 2008). In this study, teacher self-efficacy is defined as teachers' proficiency in employing new teaching strategies, effectively managing classrooms, and enhancing student engagement (Tschannen-Moran and Woolfolk Hoy, 2001). Teachers exhibiting high self-efficacy levels are more inclined to participate in professional learning, implementing innovative teaching methods during classroom instruction (Yoo and Jang, 2022). The positive relationship between teacher self-efficacy and their engagement in professional learning activities can be elucidated by the Leader–Member Exchange (LMX) theory (Thien et al., 2022). In accordance with the LMX theory, teachers' emotional energy, exemplified by factors like self-efficacy, has been observed to systematically influence their engagement in professional learning activities (Marion, 2012).

Recent empirical studies have witnessed a surge in exploring the relationship between instructional leadership and teacher professional learning, with a focus on a mediating effect of teacher self-efficacy (Thien et al., 2023). The results consistently underscore the crucial role of teacher self-efficacy as a mediator across various research contexts, such as middle schools in China (Liu and Hallinger, 2018), Turkish schools (Karacabey et al., 2022), and Malaysian secondary schools (Thien et al., 2023). As supported by a meta-analytic review conducted by Alanoglu (2022), previous studies affirmed that school principals shape teacher self-efficacy through articulating an inspiring vision for learning, effectively managing instructional programmes, and fostering a conducive learning environment within the school. This, in turn, has a cascading effect on teacher professional learning (Tschannen-Moran and Woolfolk Hoy, 2001). As such, hypotheses 3 and 4 are presented.

H3: Teacher self-efficacy has a linear and positive relationship with teacher professional learning.

H4: Teacher self-efficacy mediates the relationship between instructional leadership and teacher professional learning.

Apart from confirming earlier findings about the mediating role of teacher self-efficacy, this study aims to investigate the nonlinear relationship between principal instructional leadership and teacher self-efficacy, as well as the nonlinear relationship between teacher self-efficacy and teacher professional learning.

Complexity theory. Complexity theory, as articulated by Morrison (2002, p. 6), is characterised as 'a theory encompassing survival, evolution, development, and adaptation'. This theory is concerned with complicated scenarios involving environments, organisations, or systems where an extensive number of individual components or agents are interlinked and engaged in numerous interactions. Complexity theory is widely acknowledged in educational leadership and management literature due to the multifaceted interactions among various factors (Morrison,

2010). Nonlinear relationships acknowledge the intricate interplay of variables that may not follow straightforward patterns.

Linear relationships often oversimplify the dynamics within educational systems. Nonlinear investigations allow researchers to take a more holistic approach, considering the potential nonlinear interactions among different variables. Thus, understanding these complexities is crucial for developing accurate and comprehensive insights into educational processes. As evident in the work of Thien and Lee (2022), the non-linear results suggested that a positive school culture did not consistently lead to higher levels of teacher well-being. Instead, the importance of avoiding extremes and striving for balance to attain happiness and satisfaction should be prioritised in enhancing teacher well-being. As such, the current study was motivated to perform a robustness check of the nonlinear relationships among instructional leadership, teacher self-efficacy, and teacher professional learning. This study postulated the following three hypotheses.

H5: Instructional leadership has a nonlinear relationship with teacher professional learning.

H6: Instructional leadership has a nonlinear relationship with teacher self-efficacy.

H7: Teacher self-efficacy has a nonlinear relationship with teacher professional learning.

Figure 1 shows a proposed research model based on the seven hypotheses formulated above.

Research context. Malaysia operates an education system characterised by bureaucracy and hierarchy, closely intertwined with a top-down administrative structure (Thien et al., 2022). In Malaysia, instructional leadership takes centre stage as a pivotal component of the local educational reform strategy as stated in the Malaysia Education Blueprint 2013–2025 (Bush, 2021). Nevertheless, school principals in Malaysia encounter restricted autonomy, as the majority of decision-making and accountability obligations are vested in higher authorities at the Ministry level (Ministry of Education Malaysia, 2013). This rigid managerial structure limits the scope for school principals to fully implement their instructional leadership (Harris et al., 2017). The roles of principals are delimited by the regulations established by local education authorities, constraining their influence over decisions related to staffing, teacher training, and development (Ministry of Education Malaysia, 2013). Both Ministry authorities and school principals, including middle leaders, share the responsibility of identifying areas where teachers require professional support (Ministry of Education Malaysia, 2013). Teachers are mandated to participate in an annual 7-day, in-house training programme for professional development. These programmes are conducted by school leaders or teacher leaders who have completed courses at the district or state level. Given Malaysia's practice of a cascading delivery system, there is a potential risk of significant

information loss during in-house training programmes (Chua et al., 2020). This deficiency may contribute to uncertainties in promoting teacher professional learning (Chua et al., 2020).

According to a topographical review conducted by Adams et al. (2023), the empirical studies of principal instructional leadership, teacher attitudes (such as teacher self-efficacy), and teacher professional learning in Malaysia accounted for 15%, 5%, and 5% out of a total of 328 international and local publications respectively. However, none of these published empirical studies investigate both linear and non-linear relationships between these three variables in a single structural model simultaneously. This notable gap in the current body of literature prompted the initiation of the present study, aiming to investigate both the linear and non-linear relationships among instructional leadership, teacher self-efficacy, and teacher professional learning in primary and secondary schools in Malaysia.

Methods

Sample and procedure. A quantitative cross-sectional survey research design was utilised in this study. The targeted population was the primary and secondary school teachers presently employed in the state of Penang, Malaysia (Thien et al., 2022). The sample comprised teachers, chosen deliberately to minimise bias, as their perceptions were considered to offer a more reliable measure of principal leadership in comparison to self-ratings by principals (Hallinger and Wang, 2015). In this study, a clustered sampling approach was utilised to select data. Initially, the sample was organised into clusters corresponding to the North, Central, Northeast, and Southwest districts in Penang to warrant the representativeness of the data. Subsequently, we identified 10 accessible primary and 10 secondary schools from each district using a convenience technique (10 schools × 4 districts = 40 schools). From each selected school, 10 teachers were then randomly chosen, resulting in a targeted sample size of 400 participants in total.

This study obtained approval from the University Human Research Ethics (USM/JEPeM/20020077) and the Ministry of Education Malaysia (KPM.600-3/2/3-eras (7462)). The researchers initiated an online questionnaire using Google Forms, with the cover page of the questionnaire clearly stating the research purpose and assuring the confidentiality of participants’ responses. Participation was entirely voluntary. A total of 335 teachers took part in the online survey between May and August 2020, resulting in a reported response rate of 83.75%. The chosen sample size of 335 was deemed adequate, surpassing the minimum requirement of 160, as determined by the inverse square root method in partial least-squares structural equation modelling (PLS-SEM) (Kock and Hadaya, 2018).

Table 1 shows the first half of the sample are primary school teachers (167) whereas the second half are secondary school teachers (168). About 40% of the sample were working in National Type Secondary Schools with most of the teachers being Chinese. The majority of teachers were female, constituting 84.2%, while male teachers made up a smaller proportion at 15.8%. The teacher-gender ratio corresponds to the Malaysian Educational Statistics Quick Fact, which reported female teachers covered 71% of the total number of teachers at primary and secondary school levels (Ministry of Education Malaysia, 2018). Teaching experience of above 20 years was the major group of the teacher sample, followed by those with teaching experience of 11–15 years (24.2%) and 6–10 years (21.2%). The predominant group of the teacher sample had more than 20 years of teaching experience, with the next largest groups having 11–15 years (24.2%) and 6–10 years (21.2%) of teaching experience, respectively. As this study has collected data from primary and

Table 1 Sample demographic profile.

Demographics	Frequency	Percentage
<i>Number of teachers by school category</i>		
Primary school	167	49.9
Secondary school	168	50.1
<i>Number of teachers by school types</i>		
National Primary School	97	29.0
National Type Primary School	70	20.9
National Secondary School	31	9.3
National Type Secondary School	137	40.8
<i>Gender</i>		
Male	53	15.8
Female	282	84.2
<i>Teaching experience (until January 2020)</i>		
5 years and below	51	15.2
6–10 years	71	21.2
11–15 years	81	24.2
16–20 years	39	11.6
Above 20 years	93	27.8

secondary school teachers, we conducted a *t*-test to ensure no significant difference between the three undertaken variables across school types. The *t*-test results showed no significant difference in instructional leadership ($\Delta m = -0.040, p = 0.968$), teacher self-efficacy ($\Delta m = 0.023, p = 0.968$), and teacher professional learning ($\Delta m = 0.089, p = 0.063$) at $p < 0.05$. The findings implied all three undertaken variables were perceived similarly among the primary and secondary teachers.

Measures. This study employed Hallinger and Wang’s (2015) Principal Instructional Management Rating Scale (PIMRS) Teacher Short Form to assess principal instructional leadership. Over the past two decades, about 90% of Malaysian educational management and leadership studies have utilised the teacher form of PIMRS as a scale for gauging principal instructional leadership (Hallinger et al., 2018). The original PIMRS Teacher Short Form comprises 22 items, utilising a five-point Likert scale with one (1) equivalent to almost never to five (5) as almost always. Specifically, five items measured the dimension of defining school mission ($\alpha = 0.868$), seven items gauged the managing the instructional programme dimension ($\alpha = 0.882$), and 10 items assessed the developing a positive school climate dimension ($\alpha = 0.935$).

In this study, the brief version of the Teacher Sense of Efficacy Scale, developed by Tschannen-Moran and Woolfolk Hoy (2001), was employed to gauge teacher self-efficacy. The original scale comprises 12 items, utilising a nine-point Likert scale (1 indicates nothing to 9 indicates a great deal). Specifically, four items were allocated to measure each dimension of efficacy for instructional strategies ($\alpha = 0.860$), classroom management ($\alpha = 0.860$), and student engagement ($\alpha = 0.810$). This scale accesses teachers’ confidence and belief in their capacity to effectively manage the classroom and employ diverse teaching strategies to successfully carry out their instructional responsibilities (Tschannen-Moran and Woolfolk Hoy, 2001). Li et al.’s (2016) unidimensional scale was employed to assess teacher professional learning. This scale comprises eight items with a six-point Likert scale (1 indicates strongly disagree to 6 indicates strongly agree). One negative item (TP3) was recoded as TP3_R. The modified version employed in this study demonstrated a reliable measure with a Cronbach’s alpha value of 0.883. Several items were modified to align with the specific context of the current study. The adapted items included Item MA3 (Make clear to the teachers who are responsible for coordinating the curriculum), PC10 (Inform parents about the

student performance in the schools), and CM4 (To what extent can you develop an effective classroom management system tailored for students seated in group arrangements?). The demographic factors, namely, gender and teaching experience, did not show any correlation with the three variables examined (refer to Appendix 1). Thus, no control variables were included in subsequent analyses.

Data estimation. This study employed the PLS-SEM approach with SmartPLS 3.2.9 software to investigate the linear and nonlinear relationships among instructional leadership, teacher self-efficacy, and teacher professional learning. The choice of PLS-SEM for data analysis was driven by two primary reasons. Firstly, PLS-SEM is particularly advantageous for simultaneously handling second-order and first-order constructs in both measurement and structural models (Hair et al., 2019; Sarstedt et al., 2020). In this study, the variables under examination—instructional leadership and teacher self-efficacy—were treated as second-order constructs, with their respective dimensions serving as first-order constructs. For instance, principal instructional leadership is a second-order construct encompassing three first-order constructs: defining the school mission, managing instruction, and developing a positive school climate. Secondly, PLS-SEM facilitates the estimation of nonlinear models depicting relationships between variables in a structural model (Rigdon et al., 2010).

This study adopted a two-step approach, following Hair et al.'s (2019) guideline, which involves first evaluating the reflective measurement model and then assessing the structural model. The investigation of relationships between latent variables and their respective items was conducted for the measurement model, focusing on first-order constructs such as teacher professional learning and all dimensions of instructional leadership and teacher self-efficacy. The second-order constructs pertain to instructional leadership and teacher self-efficacy. The reflective measurement model scrutinised the indicator reliability, assessing loadings with a threshold equal to or greater than 0.70. The validity of the reflective measurement model is contingent on both convergent and discriminant validity. Convergent validity gauges the extent to which a construct explains the variance of its items (Hair et al., 2019). To establish convergent validity, the parameter estimates of composite reliability and average variance extracted (AVE) should surpass the thresholds of 0.80 and 0.50, respectively (Hair et al., 2019). Discriminant validity, on the other hand, refers to how distinct each construct is from others in the model (Hair et al., 2019). This study employed Henseler et al.'s (2015) heterotrait monotrait ratio (HTMT) of correlations to determine discriminant validity, with an HTMT value below 0.90 indicating its establishment (Henseler et al., 2015).

Subsequently, the structural model assessment entails investigating the relationships between the variables within the model (Hair et al., 2019). In this study, a 10,000 bootstrap re-sampling technique was employed to assess the significance of hypothesis testing. The investigation delved into the effect size of the linear relationship between instructional leadership and teacher professional learning, as well as teacher self-efficacy. Following this, the predictive power of the structural model was determined through PLS_{predict} analysis to ensure its robustness (Shmueli et al., 2019). To test for nonlinear relationships, quadratic interaction terms for each linear relationship were incorporated into the structural model. The significance of these nonlinear relationships was assessed using 95% percentile confidence intervals obtained from two-tailed percentile bootstrapping with 10,000 subsamples at a significance level of $p < 0.05$ (Hair et al., 2018).

Results

Initial analysis. The initial analysis commenced with assessing multivariate skewness and kurtosis using the Web application (<http://psychstat.org/kurtosis>) (Cain et al., 2016). The findings revealed that the collected data deviated from multivariate normality, as evidenced by Mardia's multivariate skewness ($\beta = 8.078$, $p < 0.01$) and Mardia's multivariate kurtosis ($\beta = 81.398$, $p < 0.01$). Consequently, in line with Becker et al.'s (2023) recommendation, path coefficients, standard errors, t -values, and p -values for the structural model through a 10,000-sample re-sampling bootstrapping procedure were reported by the current study.

The data were collected exclusively from a single source, raising the potential concern of single-source bias (Podsakoff et al., 2003). To address this limitation, a comprehensive collinearity test was conducted by calculating the variance inflation factors (VIFs) (Kock and Lynn, 2012). In this full collinearity test, all variables were regressed against a common variable, and a VIF equal to or less than 3.3 was considered an indicator of no bias stemming from single-source data (Kock and Lynn, 2012). The analysis revealed VIF values < 3.3 for instructional leadership (1.288), teacher self-efficacy (1.247), and teacher professional learning (1.365). Consequently, single-source bias is not a significant concern in the current dataset for this study.

Regarding the instructional leadership variable, Table 2 depicts that the dimension of defining the school mission has the highest mean value ($M = 4.167$, $SD = 0.637$), surpassing the dimensions of managing the instructional programme ($M = 4.016$, $SD = 0.663$) and promoting a positive school learning climate ($M = 3.832$, $SD = 0.784$). In the case of the teacher self-efficacy variable, the highest mean values are associated with the dimension of efficacy for classroom management ($M = 7.504$, $SD = 0.935$), exceeding the dimensions of efficacy for instructional strategies ($M = 7.215$, $SD = 0.863$) and efficacy for student engagement ($M = 7.092$, $SD = 0.995$). The unidimensional teacher professional learning variable is moderately rated ($M = 4.878$, $SD = 0.782$).

Assessment of measurement model (first-order constructs). In this study, no individual item was omitted, even though the loading values for items MA7, PC1, TPL6, and TPL8 fell below the 0.70 threshold in the initial analysis. This study retained these four items because the composite reliability (CR) and average variance extracted (AVE) values for the first-order constructs of managing the instructional programme (MA), promoting a positive school learning climate (PC), and teacher professional learning (TPL) were found above the thresholds of 0.80 and 0.50, respectively. Table 2 shows the CRs and AVEs for the remaining first-order constructs also surpassed the respective thresholds of 0.80 and 0.50. The findings indicated that the convergent validity for these constructs was established. Table 3 indicates that the HTMT values are below the 0.90 threshold, confirming the discriminant validity for the first-order constructs was established.

Assessment of measurement model (second-order constructs). The loading values for the first-order constructs of each instructional leadership and teacher self-efficacy (both serving as second-order constructs) are presented in Table 4 and are all above the 0.70 threshold. Both the composite reliability (CR) and average variance extracted (AVE) values for instructional leadership and teacher self-efficacy exceed the respective thresholds of 0.80 and 0.50. In Table 3, the HTMT values, as indicated in rows 10–12, are below the 0.90 threshold. These results signify both convergent and discriminant validity for the second-order constructs were established.

Table 2 Assessment of measurement model (first-order constructs).

Item	DE	MA	PC	IS	CM	SG	TPL	Mean	SD	Alpha	CR	AVE
DE								4.167	0.637	0.900	0.939	0.793
DE1	0.835											
DE2	0.818											
DE3	0.869											
DE4	0.851											
DE5	0.850											
MA								4.016	0.663	0.855	0.911	0.595
MA1		0.837										
MA2		0.714										
MA3		0.805										
MA4		0.721										
MA5		0.852										
MA6		0.781										
MA7		0.673										
PC								3.832	0.784	0.935	0.945	0.634
PC1			0.688									
PC2			0.795									
PC3			0.761									
PC4			0.817									
PC5			0.833									
PC6			0.850									
PC7			0.811									
PC8			0.780									
PC9			0.820									
PC10			0.797									
IS								7.215	0.863	0.869	0.910	0.718
IS1				0.801								
IS2				0.864								
IS3				0.862								
IS4				0.860								
CM								7.504	0.935	0.912	0.939	0.793
CM1					0.909							
CM2					0.908							
CM3					0.922							
CM4					0.820							
SG								7.092	0.995	0.889	0.923	0.751
SG1						0.876						
SG2						0.904						
SG3						0.866						
SG4						0.819						
TPL								4.878	0.782	0.918	0.936	0.653
TPL1							0.869					
TPL2							0.890					
TPL3							0.851					
TPL4							0.882					
TPL5							0.874					
TPL6							0.654					
TPL7							0.843					
TPL8							0.512					

5-point Likert scale is used to measure DE, MA, and PC, 9-point Likert scale is used to measure TSE, 6-point Likert scale is used to measure TPL. DE defining the school mission, MA managing the instructional programme, PC promoting a positive school learning climate, IS efficacy for instructional strategies, CM efficacy for classroom management, SG efficacy for student engagement, TPL teacher professional learning, SD standard deviation, CR composite reliability, AVE average variance extracted, VIF variance inflation factors.

Assessment of structural model

Linear relationship. Figure 2 and Table 5 show that instructional leadership has a significant linear relationship with teacher professional learning ($\beta = 0.364, t = 4.275$) and teacher self-efficacy ($\beta = 0.511, t = 9.094$) at $p < 0.001$. The percentile confidence interval of both linear relationships did not contain the zero value has further supported the significant linear relationship between instructional leadership and teacher professional learning (Nitzl et al., 2016). Thus, H1 and H2 were supported. Similarly, teacher self-efficacy has a significant linear relationship with teacher professional learning ($\beta = 0.314, t = 5.780$). Hence, H3 was supported. Apart from that, teacher self-efficacy plays a significant

mediating role in influencing the relationship between instructional leadership and teacher professional learning ($\beta = 0.160, t = 4.994$) at $p < 0.001$. Therefore, H4 was supported.

Non-linear relationship. Table 5 shows that the nonlinear relationship between instructional leadership and teacher-professional learning ($\beta = 0.033, t = 1.001$) is nonsignificant at the significance level of 0.01. Thus, H5 was not supported. The findings implied that the linear relationship between instructional leadership and teacher-professional learning was robust. However, there was a significant nonlinear relationship between instructional leadership and teacher self-efficacy ($\beta = 0.181,$

$t = 5.670$) at the significance level of 0.001. Similarly, there was a significant nonlinear relationship between teacher self-efficacy and teacher professional learning ($\beta = 0.048, t = 2.074$). Thus, H6 and H7 were supported. Figures 3 and 4 illustrate a U-shape of these nonlinear relationships. Hence, H6 and H7 were supported. In terms of the significance of nonlinear relationships, the effect

size magnitude of the nonlinear relationship between instructional leadership and teacher self-efficacy was deemed substantial, with an effect size of $f^2 = 0.137$ (Kenny, 2018). In contrast, the effect size of the nonlinear relationship between teacher self-efficacy and teacher professional learning was considered relatively small with $f^2 = 0.009$.

Table 3 Heterotrait monotrait ratio (HTMT_{0.90}) (first-order constructs).

First-order construct	CM	DE	IS	MA	PC	SG	TPL
CM							
DE	0.236						
IS	0.771	0.319					
MA	0.257	0.894	0.317				
PC	0.255	0.793	0.322	0.881			
SG	0.781	0.321	0.805	0.419	0.364		
TPL	0.335	0.398	0.403	0.457	0.441	0.469	
Second-order construct	IL	TPL	TSE				
IL							
TPL	0.467						
TSE	0.378	0.453					

Table 4 Assessment of measurement model (second-order constructs).

Second-order construct	First-order construct	Loadings	Alpha	CR	AVE
Instructional leadership			0.916	0.947	0.856
	DE	0.910			
	MA	0.946			
Teacher self-efficacy	PC	0.918			
			0.876	0.923	0.800
	IS	0.895			
	CM	0.870			
	SG	0.918			

Predictive power. Figure 2 demonstrates instructional leadership contributed about 23% to teacher self-efficacy. Both instructional leadership and teacher self-efficacy contribute to about 28% of the explained variance in teacher professional learning. The extent of variance explained in teacher professional learning suggests that the in-sample predictive power is deemed satisfactory for this exploratory study.

Subsequently, the PLS_{predict} analysis (Shmueli et al., 2019) was conducted to assess the out-of-sample predictive capability. In this study, $Q^2_{predict}$ values for both the PLS and linear model (LM) results were compared, along with the evaluation of predictor error using root mean square error (RMSE) values. As depicted in Table 6, both the $Q^2_{predict}$ values for PLS and LM results demonstrate positivity. The RMSE values for PLS are smaller than their counterparts in the LM results. These findings suggest that the structural model exhibits a high level of out-of-sample predictive power.

Discussion

Linear relationship. Following previous findings (Hammad et al., 2021; Karacabey et al., 2022; Liu and Hallinger, 2018, 2021), the current finding affirms a positive relationship between instructional leadership and teacher professional learning. This result is anticipated, as principals play a crucial role in guiding the school’s direction and organising activities that encourage collaborative efforts among teachers to enhance their learning and professionalism within the school setting (Hammad et al., 2021; Zheng et al., 2019). More specifically, principals offer constructive feedback to teachers, laying the groundwork for their active involvement in professional learning opportunities (Bellibas et al., 2022). Furthermore, principals exert substantial efforts to foster professional development and motivate active teacher participation in professional learning activities (Bellibas et al., 2022). The linear relationship between instructional leadership and teacher professional learning can be regarded as robust and enduring,

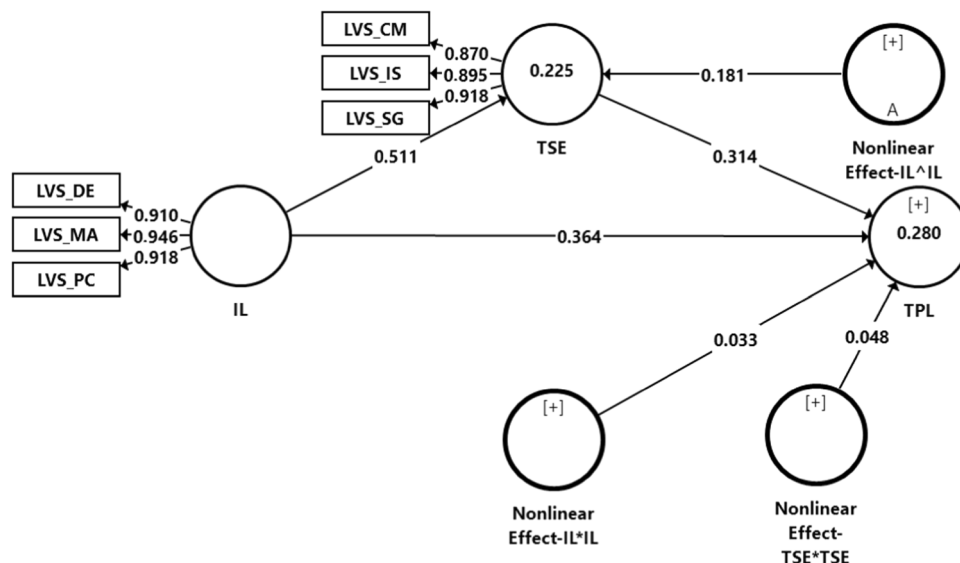


Fig. 2 Structural model.

Table 5 Hypothesis testing.

Hypothesis	Beta	SE	t-value	p-value	PCI	f ²	Supported
H1: IL → TPL	0.364	0.083	4.275	<0.001	[0.175, 0.525]	0.112	Yes
H2: IL → TSE	0.511	0.057	9.094	<0.001	[0.399, 0.623]	0.268	Yes
H3: TSE → TPL	0.314	0.055	5.780	<0.001	[0.211, 0.420]	0.087	Yes
H4: IL → TSE → TPL	0.160	0.032	4.994	<0.001	[0.102, 0.225]	0.160	Yes
H5: IL*IL → TPL	0.033	0.036	1.001	0.371	[-0.034, 0.086]	0.004	No
H6: IL*IL → TSE	0.181	0.031	5.670	<0.001	[0.110, 0.240]	0.137	Yes
H7: TSE*TSE → TPL	0.048	0.023	2.074	<0.001	[0.003, 0.095]	0.009	Yes

Bootstrapping based on 10,000 sample resampling. H1-H3 for the hypothesis testing of linear effects. H5-H7 for the hypothesis testing of nonlinear effects. PCI percentile confidence interval, f² effect size.

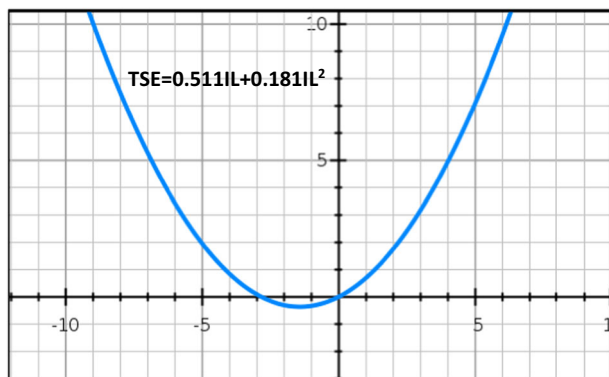


Fig. 3 Nonlinear effects of Instructional leadership on teacher self-efficacy.

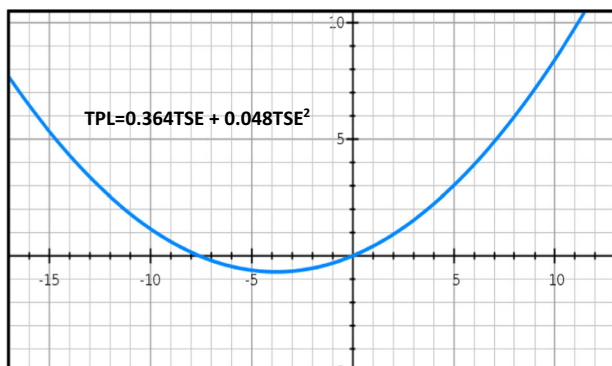


Fig. 4 Nonlinear effect of teacher self-efficacy on teacher professional learning.

given the absence of a significant nonlinear relationship, as indicated in the present study.

Consistent with prior research (e.g., Bellibas et al., 2021), this study confirms a substantial linear relationship between instructional leadership and teacher self-efficacy. This result underscores the idea that instructional leaders can set motivating objectives, encouraging teachers to actively participate in the school improvement process (Duyar et al., 2013). Besides, instructional leaders can provide constructive feedback on teaching performance by managing the instructional programme which subsequently boosts the level of teacher self-efficacy (Geijsel et al., 2009). In other words, instructional leaders are crucial in fostering the professional learning of teachers, thereby hastening the process of teachers gaining confidence in their teaching abilities.

Aligned with the LMX theory, the current finding supported a significant linear relationship between teacher self-efficacy and teacher professional learning. A possible reason could be teacher

Table 6 Results of PLS predict analysis.

Item	PLS		LM		Difference (a - b)
	RMSE (a)	Q ² _{predict}	RMSE (b)	Q ² _{predict}	
TPL1	0.856	0.096	0.860	0.113	-0.004
TPL2	0.861	0.064	0.864	0.090	-0.003
TPL3	0.837	0.096	0.843	0.118	-0.006
TPL4	0.878	0.156	0.882	0.090	-0.004
TPL5	0.931	0.122	0.933	0.073	-0.002
TPL6	1.009	0.099	1.018	0.046	-0.009
TPL7	0.957	0.13	0.963	0.706	-0.006
TPL8	1.208	0.076	1.254	1.009	-0.046
LVS_CM	0.981	0.042	0.986	0.034	-0.005
LVS_IS	0.962	0.079	0.969	0.066	-0.007
LVS_SG	0.945	0.111	0.946	0.112	-0.001

TPL1-TP8 indicated the eight items measure teacher professional learning. CM, IS, and SG indicated the three dimensions of teacher self-efficacy. CM, IS, and SG have been converted into latent variable scores (LVS).

CM classroom management, IS instructional strategies, SG student engagement.

self-efficacy strengthens teachers' confidence in participating in professional learning by improving their professional capacities. Teachers engage actively in professional learning actively when they feel they have strong capacity, skills, and motivation in teaching. The confidence in their teaching abilities reinforces their self-efficacy beliefs, subsequently influencing their active participation in professional learning. This finding aligns with Tschannen-Moran and Hoy's (2001) argument that teacher self-efficacy is a crucial psychological factor in predicting teacher professional learning. The current empirical evidence adds to the limited body of studies exploring the linear relationship between teacher self-efficacy and teacher professional learning in the existing literature.

The mediating effect of teacher self-efficacy. The impact of instructional leadership on teacher self-efficacy is more pronounced than its impact on teacher professional leadership (see Table 5, Column 7). The finding underscores the role of teacher self-efficacy as a crucial mediator linking instructional leadership and teacher professional learning, aligning with the concept of teacher self-efficacy as a 'key broker.' Consistent with previous empirical findings (Karacabey et al., 2022; Liu and Hallinger, 2018). This finding is in line with expectations, as guidance from instructional leaders is seen to enhance teacher self-efficacy, subsequently fostering teacher professional learning (Alanoglu, 2022). From the perspective of social cognitive theory (Bandura, 1997), the result affirms that instructional leaders provide support, encouragement, and collaborative opportunities for teachers to enhance their beliefs in a professional capacity. Teachers become more positive and confident about their capacity when

they are influenced by other model teachers. Moreover, once teachers believe in their strong professional capacity, they are likely to be more committed and dedicated to professional learning. This, in turn, will further improve their professional learning.

Nonlinear relationships. According to international and local publications, there has been a notable scarcity of previous educational studies that have delved into non-linear relationships within the education literature. The limited studies are evident in the higher education and school culture contexts. Ghasemy and colleagues (2021) explored the intricate non-linear associations among attributes of the work environment, work-related occurrences, emotional states, and attitudes, specifically within the landscape of higher education in Malaysia. Meanwhile, Thien and Lee (2022) revealed a non-linear relationship between school culture and teacher well-being, examining both low and high-enrolment school contexts. In fact, based on the authors' Scopus database search, the present study marks the inaugural empirical study to scrutinise non-linear relationships using PLS-SEM approach within the educational leadership literature.

The non-linear relationships suggest that the impact of principal instructional leadership and teacher self-efficacy on teacher professional learning is not a straightforward or linear process. The current findings revealed principal instructional leadership and teacher self-efficacy can interact in non-linear ways to explain the variation of teacher professional learning. As illustrated by Fig. 3, the adverse relationship at the starting point of instructional leadership on teacher efficacy might be due to the time factor in exercising leadership and the time necessary for teachers to recognise leadership in their school context, which can be attributed to the complexity of their school organisational context and atmosphere. By reasoning, school leaders might take time to be acknowledged as the leaders in the organisation, and also teachers are likely to be motivated after they have more frequent interactions with the school principal. Once instructional leaders build up positive relationships with teachers after a certain period, the impact of instructional leadership on teacher efficacy will be demonstrated. Hence, it can be drawn that teachers need time to have a clear perception of instructional leadership through interaction with school leadership, which can explain the delay in the demonstration of the effectiveness of instructional leadership on teacher efficacy.

Besides, the non-linear relationship between principal instructional leadership and teacher professional learning informs the school administrators that simply relying on the instructional school leadership and teacher self-efficacy might not be sufficient to promote teacher professional learning at the early stage (see the U-shape in Fig. 3). The adverse relationship informs that school leaders should adopt diverse strategies and tailor different interventions to promote teacher professional learning as solely relying on principal-led initiatives may not promote the full range of influences on teacher professional learning. The non-linear findings highlighted a need to consider other situational variables (Park and Gong, 2023), including school culture, teacher collaboration, and external resources, that can influence teacher professional learning. More importantly, nonlinear relationships imply that strategies in promoting teacher professional learning might only be effective within a particular timeframe but may not yield the same results in subsequent periods (Ng, 2021). The findings reflected that school improvement plans should be designed with flexibility to adapt over time as the relationship between instructional leadership and teacher professional learning may not happen linearly or predictably.

Likewise, the non-linear relationship implies that the relationship between teacher self-efficacy and professional learning may not be a linear progression. There was a point at which further increases in teacher self-efficacy had negative impacts on their professional learning at the early stage (see the U-shape in Fig. 4). The findings illustrated that when teachers possess higher self-efficacy, they could potentially fall into a state of complacency, resulting in reduced engagement with professional learning. As teachers' self-efficacy increases to a certain extent, they tend to acquire greater professional knowledge. Consequently, they become more inclined to acknowledge their teaching deficiencies. During this stage, elevated self-efficacy is more likely to drive heightened expectations for improvement, thereby encouraging greater engagement of teachers in professional learning activities.

Investigating the relationships between instructional leadership, teacher self-efficacy and professional learning could help the school stakeholders to have a better understanding of the nonlinear dynamics at play. The findings derived from the statistical models revealed the non-linear relationships allowing school leaders to make more informed decisions about school improvement initiatives. The understanding of such a non-linear relationship informs teachers with low self-efficacy may benefit from school support to enhance their confidence in their teaching abilities. Providing mentoring and coaching could foster teacher self-efficacy (Chizhik et al., 2018).

Such school improvement initiatives could assist teachers in overcoming barriers and participating more effectively in professional learning opportunities. For teachers possessing a high level of self-efficacy, there is a threshold where further enhancements in self-efficacy are likely to significantly benefit their professional learning. Consequently, school improvement initiatives should acknowledge varying levels of teacher self-efficacy and offer tailored professional learning activities that can expand and improve their teaching skills. Besides, in recognition that teacher self-efficacy and professional learning are intertwined over time, school improvement initiatives could focus on long-term sustainability. This is because providing continuous support and follow-up actions could contribute to building a cycle of growth in teacher self-efficacy and teacher professional learning.

In essence, recognising the nonlinear relationships between principal instructional leadership, teacher self-efficacy, and teacher professional learning requires school leaders to embrace complexity, flexibility, and adaptability in their school improvement efforts. By doing so, school leaders could create a more robust and effective approach to fostering teacher professional learning, enhancing teacher self-efficacy, and overall improving the professional learning of teachers.

Conclusion

This study has made a valuable contribution to the existing body of knowledge in educational leadership literature. It delves into the linear relationship between instructional leadership and teacher professional learning, followed by a robust examination of the nonlinear relationship, mediated by teacher self-efficacy. The results have advanced our understanding by revealing significant nonlinear relationships between instructional leadership, teacher self-efficacy, and teacher professional learning. What sets this study apart is its focus on a developing Southeast Asian country, Malaysia, providing novel insights that build upon previous research in the Asian region, such as studies conducted in Turkey and China (Karacabey et al., 2022; Liu et al., 2016).

Implications. This study has practical implications. The linear relationship between instructional leadership and teacher-professional learning suggests that instructional leader needs to

focus on building the organisational context for improving professional learning in their school. Concurrently, instructional leaders need to provide modelling, give positive feedback, and build up the community to advance the level of teacher self-efficacy at the school level, which in turn, contributes to teachers' participation in professional learning. Specifically, the stronger nonlinear relationship between instructional leadership and teacher efficacy indicates that school principals need to take more time to interact with teachers in the improvement process. This will improve the possibility of the recognition of their leadership practices, and in turn, contribute to the enhancement of teacher self-efficacy and their participation in professional learning. Nonlinear studies provide a more accurate basis for policy recommendations and educational practices. Local authorities and policymakers need to recognise that effective instructional leadership practices by school principals can play a crucial role in improving the academic performance of students and teacher professional learning. In fact, special consideration should be directed towards principal instructional leadership practices as the mean values of the dimensions of principal instructional leadership were moderately rated (see Table 2, Column 9). This study also has methodological implications by providing comprehensive and robust step-by-step analyses involving both linear and nonlinear analyses. Researchers in educational leadership studies could replicate this study by using a similar research method and data analysis procedure.

Limitations and future studies. This study has only investigated the 335 primary and secondary school teachers within the state of Penang, Malaysia. Hence, the generalisability of the current findings is confined to this particular setting. A larger sample size that accurately represents the targeted population is suggested for future studies to ensure the findings can be generalised. Furthermore, This study did not categorise the sample according to the school types (primary versus secondary schools) and location (urban versus rural schools). Hence, the observed linear and nonlinear results in this study may be influenced by contextual factors (Thien et al., 2023). This limitation points towards avenues for empirical studies in the future. Subsequent studies might consider utilising qualitative research methods to obtain a more profound understanding, particularly in elucidating the findings by considering school types and locations (Thien et al., 2023). While we recognise the relevance of our findings to research contexts with centralised education systems akin to Malaysia, it is important to exercise caution when extrapolating these results to diverse cultural settings, especially in developing countries (Ghasemy et al., 2021).

Furthermore, 72% of the variations in teacher professional learning are determined by other variables that are not taken into consideration in the current study. Therefore, future studies could incorporate additional independent variables, including transformational leadership and learning-centred leadership. Additionally, the inclusion of mediators such as teacher trust, teacher agency, and teacher mastery goals, as proposed by Karacabey et al. (2022), could enrich the depth and scope of future studies. In addition, as suggested by Ghasemy et al. (2020), a nonsignificant nonlinear relationship among the undertaken variables warrants an in-depth quantitative investigation using the longitudinal design using latent growth curve modelling to assess whether instructional leadership is indeed a prerequisite for achieving a high level of teacher professional leadership over a certain period. This suggestion could be a new direction for future studies.

In conclusion, the presence of significant linear and nonlinear relationships between instructional leadership, teacher self-

efficacy, and teacher professional learning has expanded the research foundation of educational leadership literature. This study is anticipated to establish a baseline reference for forthcoming research in educational leadership, employing both linear and nonlinear analyses.

Data availability

All data generated or analysed during this study are included in this published article.

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Author contributions

LMT conceptualised the study, administered the surveys, and performed the analysis. PL helped in the literature review and discussion of the manuscript. LMT and PL revised the manuscript. Both authors have read and approved the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

This research adheres to the ethical standards and guidelines outlined in the Helsinki Declaration of 1964 and its subsequent amendments. All research procedures were conducted in accordance with these ethical standards. Ethical clearance for this study was obtained from the University Human Research Ethics, Universiti Sains Malaysia, with the code number USM/JEPeM/20020077.

Informed consent

This study secured informed consent from each participant between May and August 2020. Every participant provided written consent after being adequately informed. Participation in the survey was entirely voluntary. All the responses are kept strictly confidential.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1057/s41599-023-02500-5>.

Correspondence and requests for materials should be addressed to Lei Mee Thien.

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