International Journal of Evaluation and Research in Education (IJERE)
Vol. 14, No. 3, June 2025, pp. 1577~1589
ISSN: 2252-8822, DOI: 10.11591/ijere.v14i3.32214

Development and validation of the principals' digital leadership instrument using Rasch measurement model

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Article Info

Article history:

Received Jul 24, 2024
Revised Feb 5, 2025
Accepted Feb 13, 2025

Keywords:

Instrument
Principal' digital leadership
Rasch model measurement analysis
Reliability
Validity

ABSTRACT

This study addresses the critical need for robust measurement tools in digital leadership (DL) within educational settings—a topic of increasing relevance but limited research. Using the Rasch model measurement analysis, the study aims to develop and validate an instrument tailored to assess principals' digital leadership (PDL) in China. The questionnaire, based on the five dimensions of the International Society for Technology in Education (ISTE) for education leaders—equity and citizenship advocate (ECA), visionary planner (VP), empowering leader (EL), systems designer (SD), and connected learner (CL)—was adapted to reflect Chinese cultural contexts. Following expert validation, the 33-item instrument was piloted with 188 teachers from higher vocational and technical colleges in Sichuan Province. The Rasch analysis, performed using Winsteps 3.72.3, assessed item fit, unidimensionality, local independence, reliability, separation index, and item-person mapping. The findings revealed that 26 items met all assumptions, demonstrating the strong reliability, validity, and psychometric robustness of the instrument. In conclusion, the validated PDL instrument is a reliable tool for assessing the DL of principals within the Chinese educational context, offering insights into professional development, and sets the stage for future research and policy development in the field of educational leadership.

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1. INTRODUCTION

The emerging digital technologies, including 5G, artificial intelligence (AI), big data, blockchain, augmented reality (AR), virtual reality (VR), and mixed reality (MR) [1] have profoundly changed educational practices and models, communication, and way of teaching and learning [2], posing serious threats, concerns, and challenges for educational institutions and education leaders. To remain competitive in the digital age, educational institutions must consistently anticipate and adapt to changes and challenges. Due to the pervasive integration of digital technologies into educational processes, digital leadership (DL) is imperative to support the sustainability of school improvement initiatives in the digital age and to facilitate the digital transformation of educational institutions [3]. DL is responsible for aligning the school structure, tasks, personnel, and culture with these continually changing circumstances. Educational leaders with extensive expertise and proficiency with DL are crucial in addressing the challenges that have emerged in the

digital age [4], and are likely navigating educational institutions and their stakeholders towards digital transformation, enabling them to be adaptable and competitive in a rapidly evolving digital world [5].

School principals are the most important and highly influential stakeholders in implementing DL and technology in educational institutions, they have a significant influence over resource allocation and the overall direction of their organizations [6]. In addition, they actively engage with all stages of school improvement initiatives by conveying clear expectations, inspiring, and involving teachers to create common visions that promote continuous improvement, fostering a climate of trust and collaboration as well as providing teachers with opportunities for professional growth [6], [7]. This, in turn, can boost teachers' confidence and willingness to adopt and effectively integrate more cutting-edge digital technologies in their teaching practices [8], [9], which ultimately leads to positive academic outcomes and progress for students [6].

Although DL has received a lot of attention from academics, there are few empirical studies that focus particularly on the DL practices of school administrators, and there is a dearth of research on how to measure and assess DL [10]. No studies have been conducted concerning the development and validity of an instrument for principals' digital leadership (PDL). The insufficient understanding and expertise in DL among principals hinder their ability to make well-informed decisions to support teachers in effectively integrating digital technology into educational practices [11]. It is necessary to develop measurement tools to identify and assess the extent of principals' knowledge and the variety of technology they employ [12]. Thus, this study seeks to develop a valid and reliable DL scale that can be used by school administrators to assess their own DL abilities as well as by teachers to measure the level of PDL practice based on their perspectives. Further, the flow and process of the development of the PDL instrument as well as the robust empirical evidence regarding the PDL instrument, particularly from the Rasch model perspectives, are presented.

2. LITERATURE REVIEW

2.1. Digital leadership

DL refers to the ability to set direction, influence others, initiate sustainable change through the effectively use of digital technologies, and establish relationships to anticipate changes pivotal to school success in the future [13]–[18]. According to Sheninger [16], DL is a dynamic combination of mindsets, digital skills, and behaviors that are used to bring about change, to enhance school culture and achieve goals through the effective use of digital technologies. This viewpoint is supported by several studies [8], [14], [19]. Several previous research defined DL as integration of digital technologies into leadership practices with the aim of achieving sustainable changes in educational institutions [20], [21]. DL was also described as a combination of technology, motivation, and leadership style [17] or the combination of leadership skills and digital competences [22], with the aim of establishing schools that are equipped with digital capabilities and capable of adapting to the fast-changing, digital environment.

Inevitably, DL is widely recognized as a crucial capacity for educational leaders to effectively implement digital transformation [5], [11], [13], [15], [18]. Tanucan *et al.* [5] provided a definition of DL as the ability to establish a clear vision for the adoption, implementation, and promotion of technology in the workplace. This vision serves as a guide for stakeholders and educational institutions, enabling them to adapt and stay competitive in a rapidly evolving digital environment. According to AlAjmi [6], DL refers to the capacity to effectively implement leadership strategies that are appropriate for the digital era using modern technological platforms. Also, Karakose *et al.* [22] described DL as the ability to use digital technology to create establish a well-structured system that sets direction, influences people, initiates sustainable change and builds relationships that promote significant transformations in digital education.

In the educational settings, the existing definition was predominantly concerned with using digital technologies in the functional performing leadership functions at school [23], and there are several significant elements which are commonly identified, including: i) setting the direction; ii) developing people; iii) developing the organization; and iv) developing teaching and learning [24]. In this study, DL is defined as a dynamic combination of digital thinking, mindset, behaviors, and skills that are employed to establish direction, influence others, initiate sustainable change through the effectively use of digital technologies, and establish relationships to anticipate changes that are crucial for school success in the future [13]–[18]. DL is more than just using digital technologies to perform leadership functions at schools. It also includes essential components such as possessing leadership abilities, offering professional growth opportunities, fostering digital culture, building relationships, and facilitating systemic and structural improvements [23].

Prior research has provided empirical evidence for the positive influence of principals' DL on teachers' integration of digital technologies into educational practices as well as teachers' digital competence. In their study, Hamzah *et al.* [8] examined the positive effects of PDL on teachers' digital teaching practices in Malaysia during the COVID-19 pandemic. AlAjmi [6] conducted a cross-sectional survey to further investigate the relationship between PDL and teachers' usage of digital technology in their instructional

practices. The findings indicate that PDL has a significant impact on the extent of technology integration among teachers in Kuwait during the COVID-19 pandemic. Research by Sunu [17] provided additional evidence to support the notion that teachers' adoption and acceptance of digital technology are greatly impacted by PDL. This is further supported by Tanti and Sethupathy [20], the findings of their study revealed that PDL serves as a reliable predictor of teachers' proficiency in digital teaching and their subsequent adoption of digital teaching practices. Additionally, prior research has demonstrated the beneficial effects of principals' DL on the digital competence of teachers [25], [26].

Several studies investigated the level of PDL using various instruments [5], [6], [8], [20], [27], [28]. Among these, the most frequently used instrument is the adapted principal technology leadership assessment (PTLA), which is derived from the guidelines outlined by the International Society for Technology in Education (ISTE) [29]. The study conducted by Hamzah *et al.* [8] investigated the level of PDL in Hulu Langat District, Selangor, Malaysia using PTLA with a reliability coefficient of 0.93. The study conducted by AlAjmi [6] used the PTLA [29] to evaluate the level of PDL in public elementary schools in Kuwait during the COVID-19 pandemic. Using the adapted PTLA [29] as the instrument, Zhou and Tse [28] investigated the PDL of kindergarten principals in Western China. When reviewing the literature, PTLA [29] was mostly used as a reference tool for PDL. However, it is worth noting that this instrument was created a decade ago and does not align with the most recent edition of the ISTE standard for education leaders. Several researches [5], [20], [27] investigated the level of PDL using a newly developed instrument based on ISTE [30]. However, the items were excessively long and challenging for the participants to answer. Additionally, the reliability and validity values of the instrument were not reported. It was also found that none of these studies in this field have employed the Rasch measurement model to validate the instrument. In this regard, this study seeks to develop and validate a PDL instrument using Rasch measurement analysis.

2.2. Theoretical foundation

Since 2001, the ISTE has been developing technology standards for education leaders, educators, and learners. These standards served as comprehensive road maps for effective integration of technology in educational institutions worldwide. The ISTE standards outline the fundamental competences required to become proficient in effectively using digital technology to transform the process of teaching and learning [31]. These standards offer direction to leaders and educators on how to leverage technology to create meaningful, sustainable, scalable, and equitable learning experiences [29].

Previous studies have provided evidence that the ISTE standards for administrators [29] and ISTE standards for education leaders [30] have been recognized as the predominant frameworks for measuring PDL. These standards [29] particularly served as a guide for school administrations in the implementation of digital transformation and widely cited as the conceptual framework to evaluate PDL [3], [6], [8], [28]. Other studies [5], [20] investigated the DL level displayed by principals in their research. Previous research [29], [30] provide a structure for guiding digital initiatives, with a specific emphasis on the expertise and behaviors required for leaders to empower educators and promote student learning. Furthermore, it focuses on the highly contested issues in education, including digital citizenship, visionary, innovation and cooperation, continuous improvement and professional development, lifelong learning, privacy and security. Most importantly, these topics align with the fundamental principles outlined in China's education modernization 2035 [32], such as educational equity, people-orientation, lifelong learning, ethics, integrated development, and sharing [33]. Thus, it can provide educational leaders and school administrators with valuable guidance throughout the digital transformation process [11]. In this regard, this study employed the ISTE standards for education leaders [30] as the conceptual framework foundation for the PDL instrument. The study used the definitions and indicators of the five elements of ISTE standards for education leaders [30] to conceptualize and operationalize the concept of PDL. This section discussed the theoretical foundation of the study and the five dimensions of ISTE standards for education leaders [30] that should be considered for the PDL scale which can be seen in Table 1 (see Appendix).

3. METHOD

This study used quantitative research design, employing a self-administered online questionnaire to collect data. The data collection was conducted using questionnaire star, a widely used and professional online survey platform in China. The online questionnaire was used due to its cost-effectiveness, time efficiency, and ease of administration.

3.1. Research instrument

The instrument was derived from ISTE [30], consisting of five constructs: the equity and citizenship advocate (ECA), visionary planner (VP), empowering leader (EL), systems designer (SD), and connected learner (CL). The initial instrument consists of 33 items, including 8 items for the equity and citizenship

advocate (ECA1-ECA8), 7 items for visionary planner (VP1-VP7), 5 items for empowering leader (EL1-EL5), 6 items for systems designer (SD1-SD6), and 7 items for connected learner (CL1-CL7). All the items were adapted in accordance with the definitions and the indicators of the five dimensions. A five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), was used to rate the items. The English items were subsequently translated into Chinese by an English lecture specializing in English Chinese translation using back-to-back translation.

3.2. Sampling

The pilot study was conducted out in four public higher vocational and technical colleges located in Sichuan Province, China. To conduct the Rasch measurement model analysis on the data from the pilot study, the number of samples was estimated using the sample determination table developed by Linacre [34]. According to Linacre [34], the minimum sample size of 100 respondents was necessary to achieve a confidence level of 95% with a precision of ±0.5 logit. A total of 200 samples were randomly selected in the four schools, a total of 200 online survey questionnaires were distributed to them respectively with the assistance of the human resources departments of the four colleges. In the end, 188 questionnaires were returned, resulting in a 94% response rate.

4. RESULTS

This section begins by addressing content and face validity, establishing the foundational appropriateness of the PDL instrument. Following this, a comprehensive validation process was conducted, which included the assessment of item fit, unidimensionality, and local independence. Additionally, reliability and separation index, as well as the item-person map, were analyzed using Winsteps 3.72.3 to rigorously validate the effectiveness and precision of the PDL instrument.

4.1. Content and face validity

After constructing the instrument, five expert panels were appointed to verify its content using a purposive sampling technique. These panels included two field experts and three professional experts: two professors with over 10 years of experience in educational leadership, a lecturer with a background in educational leadership from the institute of teacher education, a principal with over eight years of experience in a primary school in China, and a Ph.D. holder affiliated with the Ministry of Education in Malaysia. The experts reached a consensus that all items were acceptable, though some required rewording. The findings indicate that the items were well-conceptualized and operationalized, making them suitable for the pilot study. Subsequently, two bilingual language experts were selected to assess the face validity, also using purposive sampling.

4.2. Construct validity

Data analysis was conducted using the Rasch measurement model with Winsteps 3.72.3. Key aspects were assessed include item fit, item polarity, unidimensionality, local independence, reliability, and separation index, and the item-person map to validate the construct of the instrument. The results confirmed that the instrument exhibits strong construct validity, demonstrating its effectiveness and reliability in accurately measuring the intended constructs.

4.2.1. Item fit and item polarity

Item fit is employed to determine how well the items in the instrument fit with the Rasch measurement model [35]. According to Linacre [36], the acceptable range for the mean square standardized infit and outfit (MNSQ) for Likert scales is from 0.50 logits to 1.50 logits, with normalized and standardized infit and outfit (ZSTD) values ranging between -2.0 and +2.0 [37]. ZSTD values can be disregarded if the MNSQ values are acceptable [38]. Items with MNSQ values exceeding 1.5 are considered as underfit items, suggesting they are inconsistent with other items on the same measuring scale. These underfit items were considered confusing, respondent with high or low abilities might respond to these items correctly or incorrectly and should be revised or deleted [35]. Items with MNSQ values below 0.50 indicate overlap with other constructs. The MNSQ value is determined by considering both the infit and outfit values. This ensures that only the items that conform to the model are included in the subsequent analysis, while items that do not fit the model are considered weak and do not contribute to the evaluation of constructs [35]. Table 2 presents the fit statistics of the items.

As shown in Table 2, the infit MNSQ values range from 0.56 to 2.33 logits, while the outfit MNSQ values span from 0.50 to 2.74. Most of these values fall within the acceptable range of 0.5 to 1.5 logits, as recommended by Kamaruddin and Matore [35], suggesting that most items fit the model well. However, item

MNSQ value of ECA1, ECA2, ECA3, ECA6 exceed 1.5, indicating that these items are underfit. These items, which address principals' roles in ensuring access to technology and cultivating safe digital practices, may provide a different understanding to higher vocational and technical colleges teachers and should be revised or removed. The items are ECA1, "My principal ensures that all students have skilled teachers who actively use digital technology to meet students learning needs." ECA2, "My principal ensures that all students have access to digital devices to participate in authentic learning opportunities." ECA3, "My principal ensures that all students have access to connectivity necessary to participate in engaging learning opportunities." ECA6, "My principal cultivates the safe use of digital technology." These four items, adapted from the equity and digital citizenship advocate dimension [30], are fundamental requirements for educational leaders; hence, the four items were revised to better fit the Rasch measurement model.

Additionally, item fit can be also measured by item polarity, which is typically measured using the point-measure correlation (PTMEA Corr.) value [39]. A PTMEA Corr. value should be positive and greater than 0.3 [40], with higher values indicating the item's ability to effectively differentiate respondents' abilities. while values of zero or negative values indicate that they are misfit items [38] and should be revised or removed. In this study, all PTMEA Corr. values fall between 0.51 and 0.76, meeting the minimum requirement, indicating that all items are measurable, differentiate respondents, and contribute to the psychometric properties of the PDL instrument.

Table 2. Fit statistics of measurement items

Items	Raw score	Total count	Measure	Model error	Infit		Outfit		PT-measure	
					MNSQ[1]	ZSTD[2]	MNSQ[1]	ZSTD[2]	Corr.	Exp.
VP5	742	188	0.68	0.13	0.86	-1.2	0.81	-1.3	0.83	0.81
ECA1	744	188	0.64	0.13	1.62	4.3	2.01	5.4	0.72	0.81
VP3	753	188	0.49	0.13	0.87	-1.1	0.82	-1.2	0.82	0.80
VP2	759	188	0.38	0.13	0.99	0.0	1.01	0.1	0.79	0.80
VP6	762	188	0.32	0.14	1.04	0.4	1.06	0.4	0.79	0.79
VP1	763	188	0.31	0.14	1.13	1.0	1.23	1.4	0.77	0.79
VP4	763	188	0.31	0.14	0.79	-1.7	0.74	-1.8	0.82	0.79
CL1	763	188	0.31	0.14	0.75	-2.1	0.75	-1.7	0.82	0.79
VP7	767	188	0.23	0.14	0.90	-0.8	0.82	-1.2	0.81	0.79
EL1	767	188	0.23	0.14	0.85	-1.2	0.77	-1.5	0.81	0.79
SD5	768	188	0.21	0.14	0.89	-0.9	0.78	-1.4	0.80	0.79
ECA4	771	188	0.16	0.14	1.24	1.8	1.12	0.8	0.76	0.79
EL5	771	188	0.16	0.14	0.56	-4.0	0.50	-3.7	0.85	0.79
CL2	776	188	0.06	0.14	0.72	-2.4	0.75	-1.6	0.82	0.78
EL3	777	188	0.04	0.14	0.69	-2.7	0.68	-2.1	0.82	0.78
CL6	777	188	0.04	0.14	0.64	-3.2	0.65	-2.4	0.83	0.78
CL5	778	188	0.02	0.14	0.70	-2.5	0.70	-1.9	0.82	0.78
ECA3	779	188	0.00	0.14	2.33	7.6	2.09	5.0	0.65	0.78
SD2	779	188	0.00	0.14	0.62	-3.4	0.57	-3.0	0.83	0.78
CL4	779	188	0.00	0.14	0.69	-2.6	0.66	-2.2	0.82	0.78
EL2	783	188	-0.08	0.14	0.67	-2.8	0.62	-2.5	0.82	0.77
SD1	785	188	-0.12	0.14	0.73	-2.3	0.65	-2.2	0.81	0.77
CL3	785	188	-0.12	0.14	0.74	-2.2	0.81	-1.1	0.80	0.77
SD6	786	188	-0.14	0.14	0.83	-1.4	0.83	-0.9	0.79	0.77
SD3	788	188	-0.18	0.14	0.72	-2.3	0.78	-1.3	0.81	0.77
ECA2	789	188	-0.20	0.14	2.00	6.1	2.74	6.8	0.64	0.77
CL7	789	188	-0.20	0.14	0.82	-1.4	0.83	-1.0	0.79	0.77
ECA5	794	188	-0.30	0.14	1.35	2.5	1.49	2.4	0.71	0.76
EL4	798	188	-0.38	0.15	0.75	-2.1	0.71	-1.6	0.80	0.76
SD4	798	188	-0.38	0.15	1.24	1.8	1.06	0.4	0.73	0.76
ECA6	817	188	-0.80	0.15	1.60	4.1	1.86	3.2	0.65	0.73
ECA8	819	188	-0.85	0.15	1.12	1.0	1.04	0.3	0.71	0.73
ECA7	820	188	-0.87	0.15	1.31	2.3	1.21	1.0	0.68	0.73
Mean	778.5	188	0.00	0.14	0.99	0.4	1.01	-0.3		
S.D.	18.6	0.0	0.37	0.01	0.40	2.8	0.50	2.4		

Note: [1]Mean square; [2]Z-score standardized; ECA=equity and citizenship advocate; VP=visionary planner; EL=empowering leader; SD=systems designer; CL=connected learner

4.2.2. Unidimensionality

Unidimensionality, a fundamental assumption for construct validity in Rasch model analysis, ensures that instruments are designed to measure a single underlying construct [41]. To verify unidimensionality, principal component analysis (PCA) of residuals was used. This analysis focused on the ratio between the raw variance explained by items and unexplained variance in the first contrast, as well as the eigenvalue of the unexplained variance. For PCA, a minimum acceptable value of 20% is recommended [42]. The first principal component of the residuals should be restricted to a maximum of 10% [43], [44],

while the variance explained by the items should be at least three times greater than that explained by the first contrast [45], [46]. Moreover, the eigenvalue of the unexplained variance should be below 5 [38], exceeding this threshold indicates a potential risk to the assumption of unidimensionality. Table 3 presents the results of this analysis, providing a detailed view of how well the instrument adheres to these criteria.

Table 3. PCA of residual variance (in Eigenvalue units)

	Empirical		Modeled	
Total raw variance in observations	85.2	100%		100.0%
Raw variance explained by measures	52.2	61.3%		60.9%
Raw variable explained by persons	36.6	42.9%		42.7%
Raw variable explained by items	15.6	18.3%		18.2%
Raw unexplained variance (total)	33.0	38.7%	100%	39.1%
Unexplained variance in 1st contrast	5.5	6.4%	16.5%	
Unexplained variance in 2nd contrast	3.6	4.2%	10.8%	
Unexplained variance in 3rd contrast	2.2	2.6%	6.6%	
Unexplained variance in 4th contrast	2.1	2.4%	6.3%	
Unexplained variance in 5th contrast	2.0	2.4%	6.1%	

The PCA value of 61.3%, as shown in Table 3, indicates that the PDL instrument accounted for 61.3% of the total variance, surpassing the minimum acceptable value of 20% [42] and approaches the model expectations of 60.9%. This finding supports the unidimensionality of the scale. Furthermore, the overall noise value is recorded at 6.4%, below the maximum value of 10% [43], [44], and it is acceptable. The ratio between the raw variances explained by items (18.3%) and unexplained variance in the first contrast (6.4%) is 2.85, nearing the minimum ratio of three [45], [46]. However, the eigenvalue for the unexplained variance in the 1st contrast was 5.5, exceeding the maximum value of 5, indicating a potential second dimension.

4.2.3. Local dependence

Local independence is a crucial assumption in Rasch model analysis, serving to assess the correlation between items within the same construct [47]. According to Balsamo *et al.* [48], the correlation coefficient should ideally be below 0.30. When this threshold is exceeded, it indicates potential redundancy between items, necessitating the retention of one item and the elimination of the other. This decision is typically based on the MNSQ value, which should be close to the expected value of 1 to ensure proper model fit [36], [39]. By adhering to these criteria, retained items are ensured to be independent, thereby avoiding overlap with other items within the construct [35]. Table 4 presents a set of ten residual correlation values, providing insight into the level of independence among the items analyzed.

As demonstrated in Table 4, the residual correlation values range from 0.49 to 0.56, indicating significant correlations among items within the VP, CL, and ECA constructs. These correlations required careful consideration in deciding which items to retain, revise, or eliminate. For instance, within the visionary planner construct, items VP1 and VP2, as well as VP6 and VP7, exhibited correlations above the acceptable threshold. The decision to retain VP2 and remove VP1 was based on the MNSQ value of VP2 being closer to the expected value of 1, indicating a better fit to the Rasch model [36], [39]. Similarly, in the EL construct, EL2 was retained while EL1 was eliminated, again due to the better fit of EL2. Given that the correlation coefficients remained within the acceptable range of 0.7 [38], other items were revised or retained. For clarity, items such as VP6 and VP7 were consolidated and revised into a single item, “My principal shares lessons learned and best practices with teachers.” Item ECA 6, ECA7, and ECA8 can be merged into one sentence, that is, “My principal cultivates the responsible online behavior, including the safe, legal, and ethical use of digital technology”, aligning with the indicators outlined in previous studies [30], [32], which state that, “educational leaders cultivate responsible online behavior, including the safe, ethical and legal use of technology.” Item CL4 and CL5 were also combined to reflect support for both personal and professional growth, “my principal regularly uses digital technology to make reflections to support personal and professional growth.” Item VP2, VP6, VP7, ECA4, ECA5, EL1, CL3, CL4 are revised.

4.2.4. Reliability and separation index

Table 5 displays the reliability and separation values for both persons and items. The person reliability value is 0.92, considered very good as it falls within the recommended range of 0.91 to 0.94 [44], indicating a high probability that the items would yield consistent results with another similar respondent group [39]. The item reliability value is 0.83, deemed good since it falls within the 0.81 to 0.90 range [44], reflecting a high level of item consistency across different samples [39]. The separation values for respondents and items were 3.34 and 2.24, respectively, exceeding the minimum threshold of 2.0 [44]. This suggests that the instrument is capable of effectively segregating respondent ability and item difficulty [39].

Table 4. List of local items dependence

Correlation	Item No.-construct	Item No.-construct
0.56	VP1: visionary planner	VP2: visionary planner
0.56	CL3: connected learner	CL4: connected learner
0.55	CL4: connected learner	CL5: connected learner
0.54	VP6: visionary planner	VP7: visionary planner
0.54	ECA7: equity and citizenship advocate	ECA8: equity and citizenship advocate
0.51	ECA6: equity and citizenship advocate	ECA7: equity and citizenship advocate
0.51	CL5: connected learner	CL6: connected learner
0.50	EL1: empowering leader	EL2: empowering leader
0.49	ECA5: equity and citizenship advocate	ECA6: equity and citizenship advocate
0.56	ECA4: equity and citizenship advocate	ECA5: equity and citizenship advocate

Table 5. Reliability index and separation index

	Reliability index	Separation index
Person	0.92	3.35
Item	0.83	2.24

4.2.5. Item-person map

The item-person map, depicted in Figure 1, illustrates the distribution of items and respondents' abilities along the logits scale. Respondent abilities are positioned on the left, while item difficulty levels are on the right. Positive logit estimates on the upper left of the scale indicate more capable respondents, while items at the top right are more difficult to yield a "strongly disagree" response. Each "#" on the left side of the map refers to four respondents, while each "." represents one to three respondents [39]. The map shows that respondents' abilities spread over nearly 8 logits, indicating a wide range of responses across the Likert continuum. However, there is an imbalance between the distribution of respondents and items, with two-thirds of respondents targeted by only two items (ECA1 and VP5). This imbalance suggests that the items may not effectively differentiate between respondents with varying abilities. Additionally, items ECA6, ECA7, and ECA8 were perceived as the least challenging, whereas items ECA1 and VP5 were identified as the most difficult for respondents.

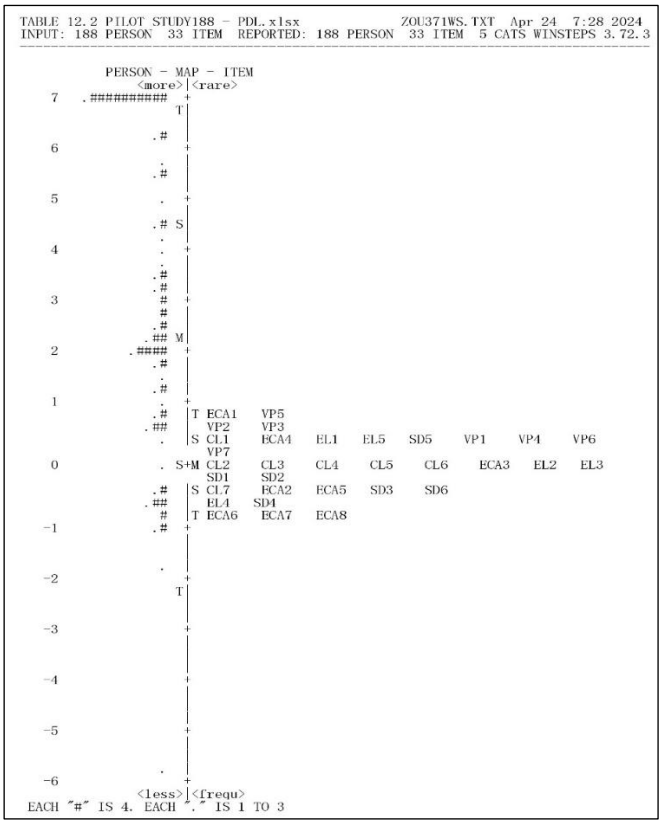

Figure 1. Item–person map for the PDL instrument analysis (Winsteps)

The research findings indicate that 29 out of the 33 items meet the infit and outfit MNSQ range of 0.5 to 1.5 set by Linacre [36], indicating that 29 items are consistent with item measurement, the other four items are revised. In addition, the PTMEA Corr. result indicates that all items have positive correlations, ranging from 0.51 to 0.76, which meets the minimal requirement of 0.30, as stated by Wu and Adams [40]. The positive PTMEA Corr. values indicate that the retained items in the PDL instrument are effective in differentiating the abilities of primary school teachers. Meanwhile, the unidimensionality of the measure is supported by the fact that it explains 61.3% of the raw variance, exceeding the minimum requirement of 20% for unidimensionality in the Rasch analysis model [42]. However, there is an unclear existence of a second dimension, as indicated by the Eigenvalue of 5.5 for the unexplained variance in the first contrast, which accounts for 7.6% of the variance. In order to enhance the quality and applicability of the scale, it is recommended to consolidate VP6 and VP7 into a single item, as well as merging ECA 6, ECA7, and ECA8 into a single item, merging CL4 and CL5 into a single item. The item-person map indicates that most of the respondents possess a high level of ability, whereas the entire items are simple. Therefore, it is necessary to develop more questions that are as challenging as those in ECA1 and VP5 to increase the overall difficulty level of the instrument, so that the abilities of the highfliers could be estimated more accurately [39].

5. DISCUSSION

This study aimed to develop and validate an instrument to measure PDL in the context of Chinese public higher vocational and technical colleges, using the Rasch measurement analysis model. The results of the study provide significant insights into the psychometric properties of the instrument and its applicability in assessing DL competencies among principals. The expert panel evaluations verified that the instrument has strong content and face validity, indicating that the items were well-conceptualized and appropriate for measuring the intended constructs. The revisions suggested by the experts, particularly regarding the rewording of some items, were crucial in enhancing the clarity and relevance of the instrument. The use of bilingual language experts further ensured that the items were culturally and linguistically appropriate for the target population. This process highlighted the importance of involving diverse expertise in the early stages of instrument development to ensure that the content is both comprehensive and contextually suitable.

The results of the Rasch analysis provided robust evidence for the construct validity of the PDL instrument. Most items fit well within the acceptable range of the Rasch model, indicating that they accurately measure the underlying constructs of the instrument. However, the identification of underfit items (ECA1, ECA2, ECA3, ECA6) related to ECA highlights areas where the instrument could be further refined. These items, although conceptually important, may require rephrasing or additional contextualization to better align with the understanding and practices of principals in public higher vocational and technical colleges in China. This finding suggests that while the instrument is generally effective, continuous refinement and context-specific adjustments are necessary to maintain its relevance and accuracy. The analysis also verified the unidimensionality of the instrument, with the majority of the variance being explained by the primary construct. However, the eigenvalue of the unexplained variance in the first contrast was slightly above the threshold, indicating the possibility of a secondary dimension. This result suggests that while the instrument predominantly measures a single construct, there may be additional underlying factors influencing the responses. Further investigation is needed to determine whether these secondary dimensions represent distinct aspects of DL or if they reflect variations in interpretation among respondents. Additionally, the local independence across items reinforces the validity of the instrument, as it indicates that the items are not overly correlated, and each item contributes unique information to the instrument of DL. This is a critical aspect of Rasch model analysis, as it ensures that the instrument provides a reliable and unbiased assessment of the construct.

The high person and item reliability index demonstrates that the instrument is capable of consistently distinguishing between respondents with varying levels of DL competence. The strong separation index further proved that the instrument is effective in differentiating between high and low performers, which is essential for its use in both research and practical applications. The slight ceiling effect observed in the item-person map, however, suggests that the instrument may benefit from the inclusion of more challenging items to better capture the abilities of respondents at the upper end of the scale. This adjustment would enhance the utility of the instrument in identifying and supporting the development of high-performing leaders.

6. IMPLICATION

The validated PDL instrument, with its strong psychometric properties, offers a valuable tool for assessing and enhancing DL competencies among principals in Chinese higher vocational and technical colleges. However, the identified areas for improvement, such as the revision of underfit items and the

enhancement of item distribution, must be addressed to ensure the continued effectiveness of the instrument. Ongoing refinement efforts are essential to maintaining its utility and ensuring it provides accurate and meaningful insights into the DL competencies required in today's educational environments. Furthermore, by identifying both the strengths and areas for improvement, this instrument holds significant potential as a strategic tool for educational administrators and policymakers. It can guide the development of more targeted and effective professional development initiatives aimed at enhancing DL. For instance, the underfit items related to equity and digital citizenship advocacy highlight the need to prioritize these areas within leadership training programs. Principals may require additional support and resources to effectively integrate these critical aspects into their leadership practices, thereby ensuring equitable access to digital learning opportunities and fostering safe, inclusive digital environments. This study emphasizes the importance of aligning training programs with well-defined DL constructs, highlighting the necessity of cultivating a culture of innovation and digital proficiency within educational institutions.

Moreover, the study underscores the ongoing need for continuous validation and refinement of assessment tools to maintain their relevance and effectiveness across diverse educational contexts. As DL evolves in response to new challenges and technologies, the PDL instrument must be periodically reviewed and updated to reflect these changes and maintain its utility in practice. Additionally, while the PDL instrument has been validated for the Chinese context, its framework holds potential for adaptation to other educational systems, enabling comparative studies and the development of DL measurement tools suited to various cultural settings. In summary, this study not only provides a robust tool for assessing DL but also offers critical insights into professional development strategies and paves the way for future research and policy development in the field of educational leadership.

7. CONCLUSION

This study aimed to develop and validate a new instrument for measuring PDL in higher vocational and technical colleges within the Chinese context. The PDL instrument was constructed based on the five dimensions of the ISTE for education leaders—ECA, VP, EL, SD, and CL. To ensure the accuracy of the instrument in measuring these constructs, both content validity and face validity were assessed, with five expert panels affirming the strong operationalization and conceptualization of the items. Additionally, Rasch measurement model analysis was utilized to assess construct validity, focusing on item fit, unidimensionality, local independence, item polarity, reliability, separation index, and item-person mapping. The Rasch analysis indicated that the developed PDL instrument is both reliable and valid for measuring the DL skills of principals in the Chinese educational context. These findings suggest that the instrument can serve as an effective tool for assessing and enhancing DL among educational leaders in China, contributing to the advancement of educational practices in the digital age. Further studies could explore the application of this instrument in different educational contexts to broaden its generalizability and impact.

However, several limitations should be acknowledged. First, the samples for the pilot study were confined to higher vocational and technical college teachers from the urban region of Sichuan Province, China, limiting the generalizability of the findings to populations with similar characteristics. Expanding future research to include participants from other regions and systematically comparing item responses across varying levels of respondents' abilities is essential. Second, the item-person map analysis indicated that the current items may not effectively differentiate between respondents with high and low ability estimates. Future studies should consider incorporating more challenging items and expanding the sample to include participants from rural and remote areas to enhance the discriminatory power of the instrument. Third, this study focused exclusively on teachers' perceptions of PDL. It is strongly recommended that future research explores principals' perspectives to provide a more comprehensive understanding of PDL. Lastly, to achieve more consistent and robust findings, further research should employ structural equation modeling (SEM) techniques to evaluate the construct validity of the instrument.

FUNDING INFORMATION

No funding was involved in this research.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
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R : **R**esources
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O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest as a result of this study.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The studies involving human participants were reviewed and approved by Faculty of Education, Universiti Kebangsaan Malaysia (UKM). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

DATA AVAILABILITY

The data presented in this study are available on request from the corresponding author, [BSA]. The data is not publicly available due to the risk of identification of study participants.

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APPENDIX

Table 1. A PDL scale

Construct	Items
ECA	1. My principal ensures that all students have skilled teachers who actively use digital technology to teach students
	2. My principal ensures that all students have access to digital devices and network connectivity for learning
	3. My principal acts as a role model for digital citizenship by critically evaluating online resources
	4. My principal acts as a role model for digital citizenship by engaging in online interactions
	5. My principal cultivates the responsible online behavior, including the safe, legal, and ethical use of digital technology
VP	1. My principal engages teachers in creating a strategic plan on how to use digital technology to enhance teaching and learning
	2. My principal evaluates progress on the strategic plan for using digital technology to improve teaching and learning
	3. My principal evaluates the impact of using digital technology to improve teaching and learning
	4. My principal gathers feedback on the strategic plan from faculty members to continually improve the strategic plan
	5. My principal shares lessons learned and best practices with teachers
EL	1. My principal builds teachers' competence to use digital technology in teaching and learning
	2. My principal inspires a culture of innovation and collaboration for teachers to use digital technology in teaching and learning
	3. My principal supports teachers in using digital technology to advance learning that meets the diverse needs of individual students
	4. My principal adopts personalized learning assessment to provide real-time feedback on students' progress
SD	1. My principal leads teams to collaboratively establish infrastructure needed to implement the strategic plan
	2. My principal leads teams to collaboratively establish systems to implement the strategic plan
	3. My principal ensures that digital technology resources for learning are sufficient to meet future demand
	4. My principal protects security by ensuring that all members follow the data management policies
	5. My principal establishes partnerships with educational institutions (e.g. universities, educational administration department, sister schools) to support the strategic plan
	6. My principal establishes partnerships with technology supplier to improve operations
CL	1. My principal sets goals to keep up with the latest digital technology
	2. My principal set goals to keep up with innovation in pedagogy
	3. My principal regularly participates in online professional learning networks to learn with other professionals
	4. My principal regularly uses digital technology to make reflections to support his personal growth and teachers' professional growth (e.g., sharing insights on online social media, webinars, digital teaching and learning platforms)
	5. My principal develops skills needed to navigate changes in digital teaching and learning
	6. My principal promotes a mindset of continuous improvement for how technology can improve learning

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