Development and Validation of a Principal Performance Assessment Instrument to Support Technology-Enhanced Biology Learning and Environmental Literacy in Secondary Schools

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Abstract: This study aims to develop and validate a performance assessment instrument for school principals to evaluate their effectiveness in supporting technology-enhanced biology learning and environmental literacy at the secondary school level. The research employed a Research and Development (R&D) approach consisting of four major phases: needs analysis, construct formulation and indicator development, expert validation, and field testing. The instrument was constructed based on nine domains of instructional leadership relevant to 21st-century biology education: learning outcomes, curriculum management, content organization, learning processes, independent learning, technological support, supervised learning visits, adaptability in instructional implementation, and learning evaluation. Expert judgment indicated strong content validity across all domains, with minor revisions suggested for clarity. Field testing conducted in several secondary schools demonstrated that the instrument possesses high internal consistency, indicating reliable measurement. The findings reveal that the instrument is capable of capturing critical dimensions of leadership performance that influence the quality of biology learning, particularly in relation to technology integration and environmental literacy. The developed instrument is recommended for use as an evaluative tool and as a basis for designing professional development programs to enhance school principals' capacity to lead adaptive, contextual, and sustainability-oriented biology education.

Keywords: Principal performance, Instructional leadership, Biology education, Environmental literacy, Educational technology

INTRODUCTION

The emergence of Digital Era 5.0 brings both opportunities and challenges for secondary education, especially in science disciplines such as biology. In this era, biology learning extends beyond mastering concepts and factual knowledge to include cultivating environmental literacy, critical thinking, and integrating digital technology meaningfully into learning processes. Biology education is therefore positioned as a strategic medium for fostering students' understanding of complex ecological systems, sustainability issues, and responsible decision-making, supported by technology enhanced pedagogical practices (Sá & Serpa, 2022; Tundo & Griguol, 2018).

Within this evolving educational landscape, school principals occupy a pivotal role. As instructional leaders, principals are not only responsible for administrative management but also for shaping the instructional vision, guiding pedagogical practices (Riyatuljannah, 2020), and ensuring that teaching and learning align with contemporary educational demands (Mbhiza, 2021). Recent studies emphasize that instructional leadership and technology-oriented leadership significantly influence teachers' instructional quality, the effective use of digital tools, and student learning outcomes (Rabillas *et al.,* 2024). In the context of biology education, this leadership role becomes even more critical, as principals are expected to support inquiry-based learning, facilitate access to digital learning resources, and promote environmental awareness as an integral part of the curriculum (Lazufa *et al*., 2022).

Despite strong policy commitments toward digital transformation and sustainability-oriented education, a persistent gap remains between policy aspirations and practical evaluation mechanisms at the school level. In many secondary schools, principal performance evaluation systems continue to rely on generic administrative indicators that inadequately capture leadership dimensions related to instructional quality, technology integration, and environmental literacy. Consequently, evaluations often fail to provide meaningful feedback for professional development or evidence-based decision-making (Ng & Seong, 2019).

This limitation is particularly evident in the assessment of principals' support for biology learning in the Digital Era 5.0. While teachers are increasingly required to integrate digital technologies and environmental themes into their instruction, principals' leadership in facilitating these processes is rarely measured using specialized, validated instruments (Fu *et al*., 2021; Riyatuljannah, 2020). As a result, leadership practices that directly influence biology teaching quality, such as curriculum alignment, instructional supervision, and the strategic use of technology, remain underexamined in formal evaluation systems.

Research on environmental literacy assessment further highlights this challenge. Existing studies indicate that environmental literacy instruments used in educational research are highly diverse, employ varying conceptual frameworks, and often lack standardization across contexts (Hussain *et al*., 2024; Kirana *et al*., 2022). Many instruments are developed for specific research purposes and are not designed to inform school-level leadership evaluation or improvement programs. This diversity limits cross-study comparability, complicates needs analysis, and weakens the potential for large-scale, data-driven interventions aimed at strengthening environmental literacy in schools.

From a measurement perspective, the absence of standardized and validated instruments poses a serious concern. Instrument development literature consistently emphasizes that evaluation tools must demonstrate robust evidence of validity and reliability to ensure that measurement results are trustworthy and meaningful for decision-making (Ain *et al*., 2025; Takom *et al*., 2017). Content validity, typically established through expert judgment, ensures that instrument items adequately represent the intended constructs, while reliability, such as internal consistency, indicates the stability and coherence of measurement across items (Dahlan & Kurniawati, 2021). Without these psychometric properties, evaluation outcomes risk being misleading or unusable for professional development and policy formulation.

More specifically, there is still a limited number of principal performance assessment instruments that integratively measure instructional leadership in biology, support for technology integration, and the promotion of environmental literacy within a single, coherent measurement framework for secondary schools (Gusho *et al*., 2023; Riyatuljannah, 2020). Existing principal evaluation instruments tend to focus on broad leadership competencies or managerial tasks, offering little insight into how principals support subject-specific instructional practices or sustainability-oriented learning (Leithwood *et al*., 2019). This limitation leads to evaluations that overlook leadership dimensions most decisive for improving technology-based and environmentally responsive biology learning.

The lack of integrative instruments also weakens the alignment between leadership evaluation and instructional improvement. Studies in educational leadership suggest that evaluation systems are most effective when they are closely linked to instructional goals and provide actionable feedback that supports professional learning (Darling-hammond *et al*., 2022). When principal performance assessments fail to address instructional leadership in specific subject areas, such as biology, opportunities for targeted leadership development are lost.

In response to this gap, the present study positions principal performance measurement as an integral component of strengthening the quality of biology learning in secondary schools. Rather than treating evaluation as a summative or compliance-oriented process, this study adopts a developmental perspective, viewing assessment as a tool for diagnosing leadership strengths, identifying areas for improvement, and informing professional development initiatives. Particular emphasis is placed on leadership support for technology integration and the enhancement of environmental literacy dimensions that are frequently marginalized in conventional performance evaluations but are central to biology education in the Digital Era 5.0.

The instrument developed in this study does not merely assess principal performance in a general or administrative sense. Instead, it is grounded in nine instructional leadership domains that are theoretically and empirically relevant to 21st-century biology learning: (1) learning outcomes, (2) curriculum management, (3) content organization, (4) learning processes, (5) self-directed learning, (6) technology support, (7) instructional supervision through classroom visits, (8) adaptability in implementation, and (9) learning evaluation. These domains reflect a comprehensive view of instructional leadership that integrates pedagogical, technological, and sustainability-oriented dimensions (Khairunnisa Putri Alif *et al*., 2022; Tang, 2023).

The selection of these domains is informed by contemporary frameworks of instructional leadership and digital leadership, which emphasize the alignment of curriculum, instruction, assessment, and technology use to enhance student learning outcomes (Huang *et al*., 2024; Lazufa *et al*., 2022). In the context of biology education, these domains also capture leadership practices that support inquiry-based learning, environmental problem-solving, and the development of students' ecological awareness.

Methodologically, this study employs a Research and Development (R&D) approach, which is widely recognized as appropriate for producing educational instruments with strong psychometric foundations. The development process follows a systematic sequence that includes needs analysis, construct and indicator formulation, expert validation, and field testing. Needs analysis ensures that the instrument addresses contextual demands and gaps in existing evaluation practices, while expert validation provides evidence of content relevance and clarity. Field testing allows for empirical examination of reliability and the refinement of instrument items based on actual school data (Borg & Gall, as cited in educational R&D literature).

Through this rigorous development process, the study produces an instrument that demonstrates strong content validity and acceptable internal consistency, supporting its use as both an evaluative and developmental tool. Beyond its immediate application for assessing principal performance, the instrument offers a foundation for designing targeted professional development programs aimed at strengthening principals' capacity to lead adaptive, technology-enhanced, and sustainability-oriented biology learning.

In sum, this study contributes to the field of biology education and educational leadership by addressing a critical gap in principal performance evaluation. By integrating instructional leadership, technology support, and environmental literacy within a single validated framework, the developed instrument responds to the demands of the Digital Era 5.0 and provides a practical tool for improving leadership practices and learning quality in secondary schools.

RESEARCH METHODS

This study employed a Research and Development (R&D) design to develop and validate a principal performance assessment instrument for supporting technology-based biology learning and environmental literacy. Unlike experimental or correlational studies that focus on testing relationships among variables, R&D research emphasizes the systematic development of educational products through iterative refinement. In this study, the R&D framework summarized from Borg and Gall was adopted because it provides a structured sequence of activities that ensures the resulting instrument is both theoretically grounded and empirically sound. The use of an R&D approach is particularly relevant for instrument development, as it facilitates the integration of theoretical constructs, expert judgment, and field-based evidence to establish content validity and reliability (Ain *et al*., 2025; Takom *et al*., 2017).

The research subjects consisted of five school principals representing five secondary schools in Buru Regency, Maluku. All principals had formal educational backgrounds in science or related fields and had completed principal certification programs. Their experience as principals ranged from five to more than ten years, indicating adequate leadership exposure for participating in instrument field testing. Subject characteristics were reported descriptively to support contextual interpretation while maintaining participant confidentiality.

Table 1. Research Sites and Participants

No.	School Name	School Type	Highest Education	Teaching Background	Years of Experience as Principal	Certification Status
1	SMAN 5 Buru	Senior High School (SMA)	Master's Degree (M.Ed./M.Sc.)	Biology / Science Education	≥ 5 years	Certified Principal
2	SMK Alhilal Namlea	Vocational High School (SMK)	Master's Degree	Science / Related Field	≥ 5 years	Certified Principal

3	SMAN 1 Buru	Senior High School (SMA)	Master's Degree	Biology / Science Education	≥ 10 years	Certified Principal
4	SMKN 7 Buru	Vocational High School (SMK)	Bachelor's / Master's Degree	Science / Related Field	≥ 5 years	Certified Principal
5	SMAN 3 Buru	Senior High School (SMA)	Master's Degree	Biology / Science Education	≥ 10 years	Certified Principal

The development process consisted of four main stages: (1) needs analysis, (2) construct and indicator formulation, (3) expert validation, and (4) field testing. Each stage was conducted sequentially to ensure that the instrument development followed a logical and systematic progression.

The needs analysis aimed to identify key dimensions of principal performance that are essential for supporting technology-based biology learning and strengthening environmental literacy in secondary schools. This stage involved a comprehensive review of relevant literature on instructional leadership, technology integration in biology education, and environmental literacy. In addition, a contextual analysis of school practices was conducted to examine existing evaluation mechanisms for principal performance and to identify gaps between policy expectations and actual assessment practices.

The findings from the needs analysis indicated that existing principal performance evaluation instruments tend to focus on general administrative and managerial competencies, with limited attention to instructional leadership in subject-specific contexts, particularly biology. Furthermore, dimensions related to leadership support for technology integration and environmental literacy were found to be underrepresented or assessed in a fragmented manner. These findings provided the empirical and theoretical basis for defining the constructs and domains of the instrument.

Based on the needs analysis, the instrument was constructed around nine instructional leadership domains relevant to 21st-century biology learning: (1) learning outcomes, (2) curriculum management, (3) content organization, (4) learning processes, (5) self-directed learning, (6) technology support, (7) instructional supervision through classroom visits, (8) implementation adaptability, and (9) learning evaluation. These domains were selected to represent the core leadership functions required to support biology learning that is adaptive, technology-enhanced, and sustainability-oriented.

Each domain was further elaborated into specific indicators that describe observable and measurable aspects of principal performance. The indicators were then translated into item statements using clear and unambiguous language to ensure ease of understanding by respondents and to facilitate accurate measurement. The formulation of indicators was guided by principles of content representativeness and construct clarity to ensure that each item adequately reflected the intended domain (Darling-hammond *et al*., 2022; Tang, 2023).

Expert validation was conducted to examine the content validity of the instrument. This stage involved a panel of experts with backgrounds in biology education, educational leadership, and educational evaluation. The experts were asked to assess each item in terms of its relevance to the corresponding domain, clarity of wording, and suitability for measuring principal performance in the context of biology learning.

To enhance objectivity in the validation process, content validity was quantified using the Content Validity Index (CVI). Item-level CVI (I-CVI) was calculated to determine the proportion of experts who rated each item as relevant, while scale-level CVI (S-CVI) was used to summarize the overall content validity of the instrument. Items with low I-CVI values were reviewed and revised based on expert feedback, focusing on improving clarity, alignment with the domain, and contextual appropriateness (Ain *et al*., 2025). This quantitative approach to content validation is widely recommended in instrument development studies because it provides a transparent and systematic basis for decision-making regarding item retention, revision, or deletion (Takom *et al*., 2017).

Following expert validation and revision, the instrument was subjected to field testing to obtain empirical data and to examine its reliability. The field test was conducted in five secondary schools, including senior high schools and vocational schools, located in Buru Regency, Maluku, Indonesia. These schools were selected to represent diverse school types and contexts within the region.

The participants in the field test consisted of five school principals, with one principal representing each school. The principals completed the instrument according to the scoring rubric provided. In cases where verification was required, the researcher cross-checked responses with available school documents and observations to ensure accuracy.

Two main data collection techniques were employed in this study. First, expert validation sheets were used to collect data on item relevance and clarity for content validity analysis. Second, the principal performance assessment instrument was administered during the field testing stage to collect empirical data for reliability analysis and descriptive evaluation. The instrument was designed in the form of a rubric-based scale, allowing respondents to rate performance levels for each indicator in a structured manner.

Table 2. Data Collection Techniques and Purposes

No.	Data Source	Instrument	Respondents	Data Collected	Purpose of Data Collection
1	Expert judgment	Expert validation sheet	Experts in biology education, educational leadership, and educational evaluation	Ratings of item relevance, clarity, and domain alignment	To examine content validity of the instrument using the Content Validity Index (CVI)
2	Field test	Principal performance assessment instrument (rubric-based)	School principals (n = 5)	Performance scores for each indicator across instructional leadership domains	To obtain empirical data for reliability analysis (internal consistency)
3	Field verification	Supporting school documents	Researcher	Confirmation of responses and scoring accuracy	To enhance the accuracy and credibility of field test data

		and researcher verification			
4	Descriptive assessment	Aggregated instrument scores	School principals	Mean scores and percentage distributions per domain	To describe principal performance profiles and identify areas of strength and improvement

Data analysis focused on examining the validity, reliability, and descriptive characteristics of the instrument. Content validity was analyzed using the Content Validity Index (CVI), including I-CVI and S-CVI, to quantify expert agreement on item relevance. Reliability analysis was conducted using Cronbach's alpha to assess the internal consistency of the instrument based on field test data. Cronbach's alpha was selected because it is widely used and recommended for evaluating the consistency of multi-item instruments in educational research (Sijtsma & Pfadt, 2021).

In addition to validity and reliability analysis, descriptive statistics were used to summarize performance scores across the nine instructional leadership domains. Mean scores and percentage distributions were calculated to facilitate interpretation of principal performance profiles and to identify domains that demonstrated strong performance as well as areas requiring improvement. This descriptive analysis supports the evaluative and developmental use of the instrument, providing empirical evidence that can inform targeted professional development programs for school principals.

RESULTS AND DISCUSSION

Field Trial Description

The field trial was conducted in five. Consequently, the analysis of principal performance and student character outcomes was based on data from these five schools (n = 5).

Table 3. Principal Performance by School

School	Score (%)	Category
SMK Alhilal Namlea	85.56	B
SMKN 7 Buru	84.44	B
SMAN 1 Buru	82.22	B
SMAN 3 Buru	78.89	C
SMAN 5 Buru	76.67	C

Table 3 presents the percentage scores of principal performances across the five schools. The results indicate moderate variation in performance, with scores ranging from 76.67% to 85.56. Three schools achieved a "good" (B) category, while two schools were classified as "fair" (C). These variations suggest differences in schools' instructional leadership capacity, indicating that improvement efforts may benefit from school-specific rather than uniform interventions.

Principal Performance by Dimension (Nine Domains)

Principal performance refers to the effectiveness of a school principal in leading, managing, and improving all aspects of the educational process, particularly in supporting teaching and learning (Patompo *et al*., 2023). It encompasses key responsibilities such as instructional leadership, decision-making, teacher supervision, and the ability to adapt to changes to achieve optimal learning outcomes.

Table 4 presents the principal's performance across nine key dimensions of instructional leadership, highlighting varying levels of effectiveness in each domain. Overall, the results indicate strong performance, with the highest achievement in adaptability and consistently high scores across most areas. These findings suggest that the principal demonstrates a well-rounded capacity to support and enhance instructional practices.

Table 4. Principal Performance by Instructional Leadership Domain

Dimension (Domain)	Percentage (%)
Dim1 Learning Outcomes	84
Dim2 Curriculum Management	82
Dim3 Content Organization	78
Dim4 Learning Processes	80
Dim5 Independent Learning	82
Dim6 Technological Support	82
Dim7 Supervised Learning Visits	78
Dim8 Adaptability	86
Dim9 Learning Evaluation	82

Table 4 summarizes performance across the nine instructional leadership domains. Dimension 8 (Adaptability) scored highest (86%), while Dimensions 3 (Content Organization) and 7 (Supervised Learning Visits) showed the lowest scores (78%). This pattern indicates that schools are relatively strong in adapting learning modalities but weaker in strengthening the instructional core, particularly in content organization and instructional supervision.

Student Character Outcomes by School

Table 5 presents student character results from schools that returned complete instruments. Overall scores ranged from 77.58% to 88.15. Similar to principal performance, three schools were categorized as "good" (B), while two were classified as "fair" (C).

Table 5. Student Character Outcomes by School

School	Number of Teachers	Total Score	Percentage (%)	Category
SMAN 1 Buru	10	811	88.15	B
SMKN 7 Buru	8	643	87.36	B
SMK Alhilal Namlea	10	770	83.70	B
SMAN 5 Buru	10	725	78.80	C
SMAN 3 Buru	8	571	77.58	C

These findings indicate a generally positive student character profile, although variation across schools suggests differing levels of effectiveness in fostering character development.

Reliability of the Student Character Instrument

Reliability testing of the updated student character instrument (23 items) produced a total Cronbach's alpha of 0.56, indicating moderate internal consistency. Subscale reliability coefficients were substantially lower: religiosity (α = 0.038), discipline (α = 0.001), collaboration (α = 0.260), independence (α = 0.429), and creativity (α = 0.072).

Item diagnostics identified the religiosity item "leading a prayer" (from the earlier version) as having a negative item–total correlation. Removing this item resulted in an improvement in the subscale alpha, providing empirical justification for its revision. Overall, these results suggest that while the instrument is suitable for preliminary evaluation, several subscales require further refinement to enhance construct clarity and measurement consistency.

Variation in Principal Performance and Implications for School-Based Interventions

"Principal performance scores ranged from 76.67 to 85.56, showing variation in instructional leadership capacity across schools. This variation suggests that efforts to improve learning quality are more likely to be effective when grounded in diagnostic, school-specific profiles rather than uniform, one-size-fits-all programs.

This finding aligns with recent systematic reviews emphasizing that technology-oriented school leadership influences learning quality primarily through vision-building, policy alignment, and capacity development mechanisms rather than through infrastructure provision alone (Yang *et al*., 2025). In the context of this study, differences in total scores can be interpreted as variations in systemic readiness to support technology-based biology learning oriented toward 21st-century competencies and environmental literacy.

High Adaptability but Weak Instructional Core: Dimensions 3, 4, and 7 as Bottlenecks

Analysis at the domain level revealed an uneven achievement pattern. Dimension 8 (Implementation Adaptability) achieved the highest score (86%), while Dimension 3 (Content Organization) and Dimension 7 (Supervised Learning Visits) recorded the lowest scores (both at 78%), followed by Dimension 4 (Learning Processes) at 80%.

This pattern reflects a condition in which schools demonstrate relatively high responsiveness in adjusting learning modes and procedures such as organizing online offline schedules but remain weaker in strengthening the instructional core. Specifically, weaknesses were observed in content curation, learning process design, and systematic instructional supervision.

Research on technology leadership consistently highlights that impactful technology integration requires leadership that actively reshapes teaching practices rather than merely enabling digital adoption (Yang *et al*., 2025). Curriculum, content, and supervision domains often become critical bottlenecks when they are not deliberately cultivated. Accordingly, Dimensions 3, 4, and 7 can be positioned as priority leverage points for ensuring that technology-based biology learning moves beyond procedural digitization toward meaningful instructional transformation.

Direct Implications for Biology Learning and Environmental Literacy

The relatively low score for Dimension 3 indicates that biology content organization has not yet fully emphasized essential, contextual, and technology-enriched content. In practice, this suggests that digital platforms are still frequently used as channels for transferring conventional materials rather than as tools for deepening conceptual understanding through simulations, biological modeling, or analysis of local environmental data.

Similarly, the lower scores in Dimensions 4 and 7 indicate that active learning processes and instructional supervision mechanisms are not yet optimally implemented. These dimensions are crucial for ensuring that teachers consistently apply inquiry-based, project-based, and reflective learning approaches pedagogies that are foundational to environmental literacy. Examples include scientific investigations of water quality, local biodiversity surveys, or waste management issues grounded in biological principles.

Without strengthening these three dimensions, environmental literacy initiatives risk becoming superficial, as technology functions merely as a content delivery medium rather than as a catalyst for scientific reasoning, ecological awareness, and student agency.

Student Character as a Supporting Outcome and Limits of Inference

The mean student character score was 83.12 (good category), with independence emerging as the lowest aspect (81.66). This pattern suggests that, although the overall character climate is relatively positive, students' capacity for self-directed learning remains a key challenge.

Theoretically, learning independence is closely linked to self-regulation skills such as time management, task planning, monitoring comprehension, and help-seeking behavior competencies that are especially critical in technology-based learning environments, which demand higher levels of learner autonomy than fully face-to-face instruction (Lilian *et al*., 2021; Sari *et al*., 2020). This finding reinforces the relevance of the "Independent Learning" domain in the principal performance instrument, as fostering student independence depends not only on classroom instruction but also on school-level policies related to task design, feedback systems, and parental engagement facilitated by school leadership (Zimmerman, 2002).

However, the strength of inferences drawn from student character data is constrained by instrument quality. The moderate total alpha (0.56) combined with very low subscale alphas indicates that several subscales lack sufficient internal coherence. Consequently, these results should be interpreted cautiously and used primarily to inform instrument revision rather than to represent definitive psychological constructs.

Interpreting Low Alpha Values and Methodological Justification for Instrument Revision

A total alpha of 0.56 places the student character instrument at a moderate level of internal consistency, yet the sharp contrast between total and subscale alphas (0.00–0.43) suggests that items within domains remain heterogeneous or that subscale constructs are insufficiently unidimensional. Cronbach's alpha is highly sensitive to construct structure and inter-item correlations; low values may indicate multidimensionality, poorly aligned items, or indicators that are difficult for respondents to observe consistently (Kumar, 2024; Sijtsma & Pfadt, 2021).

Item diagnostics in this study identified several problematic indicators, including situational religiosity items, discipline-related items, and creativity items emphasizing abstract risk-taking. Revising item wording, replacing highly situational indicators with frequently observable behaviors, and separating religiosity from prosocial behavior into distinct subscales are methodologically sound steps consistent with data-driven instrument development and expert review practices (Kumar, 2024; Sijtsma & Pfadt, 2021).

Content Validity: Single-Expert Review and Strategies for Strengthening Evidence

Content validity of the principal performance instrument was examined through expert judgment, resulting in minor revisions related to indicator clarity and domain alignment. Substantively, this provides initial support for content validity. However, because only one expert was involved, the available evidence is more accurately classified as expert review rather than quantitative content validity based on multi-expert consensus, such as CVI or Aiken's V indices (Ain *et al*., 2025; Takom *et al*., 2017)).

To strengthen the manuscript's methodological rigor and publication potential, future studies should involve a panel of experts representing educational leadership, biology education, learning evaluation, and educational technology. This approach would yield stronger narrative and quantitative evidence that the nine instructional leadership domains adequately represent the construct of principal leadership in supporting technology-based biology learning and environmental literacy across contexts.

Targeted Practical Implications Based on Priority Domains

Given that Dimensions 3, 4, and 7 consistently showed the lowest scores, the most strategic practical implication is to design principal development interventions around three integrated packages: content strengthening, process strengthening, and evidence-based instructional supervision.

Content strengthening may include workshops on curating biology materials that integrate local environmental issues, empirical data, and digital resources aligned with minimum quality standards. Process strengthening should focus on inquiry- and project-based learning designs supported by technology, such as simulations, virtual laboratories, and environmental data analysis, accompanied by formative assessment strategies that promote scientific argumentation. Instructional supervision strengthening requires principals to develop supervision calendars, observation instruments (online and offline), and feedback mechanisms based on instructional artifacts, such as lesson plans, recorded lessons, and learning management system logs. These strategies align with evidence showing that systematic, reflective instructional supervision—especially when supported by technology can improve teaching quality and teacher professionalism (Supriyono *et al*., 2021; Yang *et al*., 2025)

Integration of Findings with Previous Studies

The variation in principal performance across schools and the identification of weak instructional core domains (content organization, learning processes, and instructional supervision) are consistent with previous studies emphasizing that effective school leadership influences learning quality primarily through instructional focus rather than administrative efficiency alone (Chang & Pinkard, 2023; Leithwood *et al*., 2019). In technology-rich learning environments, principals' leadership is particularly critical in shaping teachers' pedagogical use of digital tools and aligning curriculum, assessment, and supervision practices (Khairunnisa Putri Alif *et al*., 2022; Yang *et al*., 2025)

The relatively high adaptability score observed in this study reflects findings by Mbhiza (2021), who argue that school leaders often respond quickly to structural or procedural changes, such as shifts to blended or online learning. However, without parallel strengthening of instructional content and supervision, such adaptability may result in superficial transformation rather than meaningful pedagogical change. Similar patterns have been reported in studies on digital leadership, where technology adoption outpaces changes in teaching practice (Abdurrahman & Nursafitri, 2022; Yang *et al*., 2025)

Low performance in instructional supervision aligns with evidence that academic supervision remains one of the most challenging leadership functions, particularly in integrating feedback with evidence from classroom practice and digital learning artifacts (Supriyono *et al*., 2021). Strengthening supervision has been shown to positively influence teacher professionalism and instructional quality when conducted systematically and reflectively.

Furthermore, the findings related to student learning independence support research indicating that technology-based learning environments require stronger self-regulation skills, which are influenced by school-level policies, assessment design, and leadership support (Zimmerman, 2002). From a measurement perspective, the moderate reliability of the student character instrument and weak subscale consistency are consistent with instrument development literature, which emphasizes iterative revision based on item diagnostics and expert review (Ain *et al*., 2025).

CONCLUSION

1. The nine-domain instructional leadership instrument successfully mapped variations in principal performance across schools (76.67-85.56) and identified priority improvement areas, particularly content organization, learning processes, and instructional supervision.
2. Student character data indicated generally positive outcomes, with learning independence as the weakest aspect, highlighting the importance of school leadership in supporting self-directed learning within technology-based biology education.
3. Reliability analysis of the student character instrument revealed moderate overall consistency but very low subscale reliability, justifying item revision and construct restructuring before further use.

SUGGESTIONS

1. Schools should prioritize principal development programs targeting Dimensions 3, 4, and 7 through coaching in biology content curation, inquiry and project-based learning design supported by technology, and evidence-based instructional supervision.

2. Future research should expand the sample and involve multiple expert validators to strengthen content validity evidence and enable more robust reliability analysis at the gmail.com item level.
3. The revised student character instrument should undergo re-piloting and subscale-level reliability analysis to ensure that construct refinement leads to meaningful improvements in internal consistency.

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