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INSTRUMENT VALIDATION OF A TRANSDISCIPLINARY RESEARCH READINESS SCALE: EVIDENCE FROM UNIVERSITIES IN MALAYSIA

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ABSTRACT

The growing complexity of global challenges, particularly those aligned with the United Nations Sustainable Development Goals (SDGs), necessitates a shift towards transdisciplinary research (TDR) that integrates diverse disciplinary knowledge and stakeholder perspectives. Despite its increasing importance, readiness for TDR among academics remains underexplored, particularly in the Malaysian higher education context. This study aims to develop and validate a comprehensive Transdisciplinary Research Readiness Scale (TRRS) to assess academic preparedness for engaging in TDR initiatives that address SDG-related issues. Drawing upon existing literature on TDR, knowledge integration, and organizational readiness, six core variables were identified: Causal, Context, Phenomenon, Intervening, Actions, and Quality, encompassing 28 sub-constructs and a total of 141 items. Data were collected from 27 academic respondents across multiple Malaysian universities. Reliability analysis using Cronbach's alpha was conducted to examine the internal consistency of the scale. The results indicated high reliability for all variables, with Causal (α = 0.833), Phenomenon (α = 0.843), Context (α = 0.863), Intervening (α = 0.886) and Actions (α = 0.869) rated as good, and Quality (α = 0.917) rated as excellent. These findings confirm the scale's robustness and its suitability for measuring readiness for TDR. These insights support the advancement of Sustainable Development Goals, particularly SDG 4 (Quality Education), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 17 (Partnerships for the Goals). The study recommends policy reform, industry collaboration, talent development, and robust monitoring systems to enhance TDR effectiveness.

Keywords: transdisciplinary research, scale validation, reliability analysis, psychometrics, SDGs

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1 INTRODUCTION

The accelerating complexity of contemporary global challenges such as climate change, urbanization, public health crises, and persistent social inequities has crystallized the need for research approaches that transcend disciplinary boundaries. Traditional disciplinary research, while foundational to knowledge generation, often struggles to generate coherent, actionable solutions to "wicked problems" that are inherently interconnected and multifaceted. These challenges require holistic frameworks that integrate not only diverse academic perspectives but also non-academic stakeholders, including industry, government, and communities. Transdisciplinary research (TDR) represents such a paradigm, defined as a collaborative research approach that co-produces knowledge across disciplines and societal actors to address real-world problems and contribute to sustainable development outcomes aligned with the United Nations Sustainable Development Goals (SDGs) (Tolksdorf, 2025; Csedő et al., 2025).

In recent years, the global scientific community has increasingly emphasized the role of TDR in facilitating sustainable innovation and societal transformation. The proclamation of the International Decade of Sciences for Sustainable Development (2024–2033) by the United Nations underscores the urgency of integrating research systems beyond traditional disciplinary silos to tackle planetary-scale issues such as climate change, biodiversity loss, and social inequality. This initiative aims to promote transdisciplinary approaches in scientific knowledge production and emphasizes knowledge co-creation with societal stakeholders from diverse sectors. Nonetheless, despite its conceptual appeal and theoretical promise, the operationalization of transdisciplinary research within academic institutions remains challenged by structural, cultural, and systemic barriers that impede its effective adoption and impact. Universities are central actors in national innovation systems and are expected to generate knowledge that informs policy and practice. In Malaysia, the research agenda of higher education increasingly recognizes the importance of innovation, sustainability, and collaborative research approaches. Funding agencies such as the Ministry of Higher Education (MoHE) and the Ministry of Science, Technology and Innovation (MOSTI) have introduced initiatives to encourage collaborative and transdisciplinary approaches in research programmes. Malaysian universities have also established centres and initiatives focusing on sustainability, digital transformation, and community-based research, which inherently adopt multi- and transdisciplinary methods. However, the implementation of TDR in Malaysian universities is still nascent, fragmented, and unevenly distributed, hindered by entrenched academic silos, disciplinary incentives, and structural barriers that perpetuate traditional research practices.

One of the primary challenges is the institutional culture within universities. Academic structures are often organized around disciplinary departments, with promotion, tenure, and evaluation systems incentivizing traditional publication outputs rather than impact-oriented, cross-sectoral research. As a result, academic silos persist, limiting interdisciplinary dialogue and obstructing the integration of diverse knowledge systems essential for TDR. These siloed structures also influence research training, with many academics lacking exposure to systems thinking, collaborative methods, and participatory engagement skills required for effective transdisciplinary inquiry. Linked to institutional culture are incentive and evaluation mechanisms that inadequately reward TDR efforts. Traditional academic metrics such as citation counts, journal impact factors, and disciplinary rankings often fail to capture the societal impact or applied relevance of TDR projects. This misalignment between evaluation systems and the goals of transdisciplinary research reduces motivation among researchers to engage in complex, long-term collaborative projects that require substantial time investments and stakeholder engagement. There is a growing body of literature emphasizing that institutional reform is necessary to align evaluation criteria with the unique demands of TDR, including recognition of co-created knowledge, community impact, and real-world problem solving.

Funding structures and administrative systems also present significant obstacles. Although Malaysian research funding mechanisms explicitly encourage collaborative projects, they often remain insufficient for the resource-intensive nature of TDR. Funding schemes are typically short-term, project-specific, and discipline-oriented, making it difficult to sustain long-term transdisciplinary initiatives. Moreover, current administrative procedures such as project registration, budget allocation, and reporting are not optimized for managing cross-departmental research that involves multiple stakeholders with diverse expectations and requirements. As a result, Malaysian universities struggle to build stable infrastructures and governance systems that can support transdisciplinary programmes at scale. Another critical challenge is stakeholder

engagement. Effective TDR demands meaningful involvement of non-academic partners, including government agencies, industry, local communities, and civil society organizations. While Malaysian universities have increasingly participated in international collaborations and community-based research, stakeholder engagement within TDR projects is often ad hoc or superficial, lacking systematic frameworks for co-design, co-production, and sustained partnership. This gap limits the capacity of transdisciplinary research to generate solutions that are not only academically robust but also socially relevant and practically implementable.

Within the broader epistemic context, research readiness for TDR hinges upon researchers' own competencies, perceptions, and preparedness to engage in integrative, collaborative inquiry. The shift from disciplinary knowledge production to transdisciplinary knowledge co-production requires new epistemic orientations, collaborative skills, and reflexivity among researchers. Transdisciplinary work demands comfort with complexity, tolerance for ambiguity, and openness to multiple ways of knowing a departure from conventional academic training. Without adequate capacity building and professional development tailored to TDR, individual academics may feel ill-equipped to initiate or participate in genuinely transdisciplinary research processes, further limiting institutional progress toward integrated research agendas. Although the literature on cross-disciplinary research is substantial, empirical measurement of readiness for transdisciplinary research remains underdeveloped especially in non-Western contexts such as Malaysia. Existing frameworks often focus on descriptive accounts of barriers and enablers, rather than systematically measuring the underlying conditions that enable effective TDR engagement. While global efforts have highlighted frameworks for evaluating interdisciplinary efforts, they are often fragmented and lack consensus regarding criteria that capture the full breadth of transdisciplinary readiness, including organizational, individual, and contextual dimensions.

Consequently, there is a pressing need for a comprehensive, empirically validated instrument that assesses readiness for transdisciplinary research among academics. Such a tool can provide diagnostic insights into institutional capacities, research preparedness, structural barriers, and enabling conditions for TDR. By identifying strengths and gaps in readiness, universities can make informed decisions about capacity-building strategies, incentive redesign, infrastructure investments, and professional development initiatives. This is particularly important for Malaysian universities seeking to align research practices with national innovation priorities and global sustainability agendas, such as the SDGs, where TDR plays an indispensable role. To address this gap, the current study aims to construct and validate a Transdisciplinary Research Readiness Scale (TRRS) tailored to the Malaysian higher education context. The scale is designed to operationalize readiness across six core constructs Causal, Context, Phenomenon, Intervening, Actions, and Quality reflecting multiple facets of organizational, cultural, and individual readiness for TDR. The purpose of the study is to provide rigorous empirical evidence on the psychometric properties of the TRRS and to establish it as a reliable tool for assessing the readiness of academics to engage in transdisciplinary research that contributes to solving complex societal challenges.

2 LITERATURE REVIEW

Transdisciplinary research (TDR) has gained increasing scholarly attention as a necessary approach for addressing complex societal challenges that transcend disciplinary, institutional, and sectoral boundaries. Prior studies consistently highlight that global sustainability challenges such as climate change, public health, digital transformation, and social inequality cannot be adequately addressed through single-discipline or even multidisciplinary approaches alone (Lang et al., 2022; Csedő et al., 2023). As a result, universities are increasingly positioned as key actors in fostering TDR capabilities, particularly through institutional structures, academic culture, and researcher readiness. However, empirical investigations into the readiness conditions that enable effective TDR to remain fragmented, particularly within developing and non-Western higher education contexts such as Malaysia.

Theoretical Underpinning: Creswell's Paradigm Model

This study is theoretically underpinned by Creswell's (2005) Paradigm Model, originally developed for qualitative inquiry but increasingly applied in mixed and quantitative research to explain complex social phenomena. The paradigm model conceptualizes research processes through six interrelated elements: causal conditions, phenomenon, context, intervening conditions, action/interaction strategies, and consequences (quality or outcomes). This model is particularly suited for transdisciplinary research, as TDR itself is

a dynamic, systems-oriented process involving multiple actors, contexts, and feedback mechanisms (Pohl et al., 2021).

By adapting Creswell's paradigm model, this study provides a theoretically coherent structure for conceptualizing transdisciplinary research readiness as an integrated system rather than a set of isolated attributes. Each construct captures a distinct yet interdependent dimension of readiness that shapes how academics and institutions engage in TDR initiatives.

a) Causal Conditions

Causal conditions refer to factors that give rise to the need or motivation for transdisciplinary research. Prior studies identify global sustainability pressures, policy imperatives, and funding requirements as key drivers motivating universities to pursue TDR (Klein, 2021; Wuelser et al., 2022). In the Malaysian context, national research agendas aligned with the Sustainable Development Goals (SDGs), Industry 4.0, and societal impact frameworks have increasingly emphasized collaborative and problem-oriented research (Ministry of Higher Education Malaysia, 2021). Empirical evidence suggests that academics are more inclined toward TDR when external demands such as funding calls, societal expectations, and policy priorities explicitly require cross-disciplinary collaboration (Rylance, 2023). Thus, causal conditions in TDR readiness encompass institutional mandates, policy drivers, and perceived relevance of complex societal problems.

b) Phenomenon

The phenomenon represents the central issue under investigation in this case, transdisciplinary research readiness among academics. Previous research conceptualizes readiness as a multidimensional construct involving cognitive, transdisciplinary engagement show that readiness is influenced by researchers' openness to epistemic diversity, willingness to collaborate, and comfort with uncertainty (Pohl & Hadorn, 2020). In higher education, readiness also includes competencies such as systems thinking, integrative problem framing, and stakeholder engagement skills (Schneider et al., 2022). However, most existing studies rely on qualitative insights or descriptive surveys, highlighting the need for validated measurement instruments that capture readiness as a structured and empirically grounded phenomenon.

c) Contextual Conditions

Context refers to the specific environmental and institutional settings in which TDR occurs. The literature consistently identifies organizational culture, governance structures, and disciplinary norms as critical contextual factors shaping transdisciplinary engagement (Kaufmann & Tummers, 2021). Universities structured around rigid departmental silos often inhibit cross-disciplinary interaction, whereas flexible organizational arrangements and supportive leadership enable TDR initiatives (Lyall et al., 2022). In Malaysian universities, contextual challenges include heavy teaching loads, performance evaluation systems favouring disciplinary outputs, and limited institutional support for long-term collaborative research (Rahman et al., 2023). These contextual conditions directly affect academics' capacity and motivation to engage in TDR, reinforcing the importance of contextual readiness as a core construct.

d) Intervening Conditions

Intervening conditions are factors that facilitate or constrain actions taken in response to the phenomenon. Prior studies emphasize institutional support mechanisms, such as funding availability, research infrastructure, professional development, and leadership commitment, as critical intervening variables (Boix Mansilla et al., 2020). Additionally, individual-level factors—including prior interdisciplinary experience, collaborative networks, and research self-efficacy—serve as important enablers or barriers to TDR engagement (Fischer et al., 2021). In the Malaysian context, the absence of structured training in transdisciplinary methods and limited incentives for stakeholder engagement have been identified as major constraints (Zainal et al., 2022). These intervening conditions shape how causal drivers are translated into concrete research practices.

e) Action and Interaction Strategies

Action strategies refer to the behaviours and practices adopted by academics and institutions to engage in TDR. Literature identifies strategies such as co-design of research agendas, cross-disciplinary team formation, stakeholder co-production, and reflexive learning processes as hallmarks of effective transdisciplinary research (Lang et al., 2022; Pohl et al., 2021). Universities that institutionalize these practices through formal platforms, research centres, and incentive systems demonstrate higher levels of transdisciplinary output and societal impact (Rai et al., 2023). However, without adequate readiness, such actions often remain symbolic rather than

transformative, underscoring the need to assess action-oriented readiness systematically.

f) Quality and Outcomes

Quality represents the consequences or outcomes of TDR processes, including both academic and societal impacts. Recent studies emphasize that quality in transdisciplinary research extends beyond traditional academic metrics to include relevance, usability, legitimacy, and societal impact (Belcher et al., 2021). High-quality TDR is characterized by robust knowledge integration, meaningful stakeholder engagement, and tangible contributions to policy and practice. However, the absence of shared quality criteria and evaluation frameworks remains a persistent challenge, particularly in higher education systems dominated by disciplinary performance indicators (Schneider et al., 2022). Measuring readiness for quality-oriented outcomes is therefore essential for aligning university research practices with national and global sustainability goals.

Conceptual Framework

Drawing on Creswell's paradigm model and prior empirical studies, this study conceptualizes transdisciplinary research readiness as a systemic interaction among causal drivers, institutional and individual contexts, enabling or constraining intervening conditions, strategic research actions, and quality-oriented outcomes. The six constructs Causal, Phenomenon, Context, Intervening, Actions, and Quality collectively represent the conditions under which academics are prepared to engage effectively in transdisciplinary research. This conceptual framework provides a theoretically grounded basis for developing and validating the Transdisciplinary Research Readiness Scale (TRRS), offering a structured approach to understanding and enhancing TDR capacity in Malaysian universities.

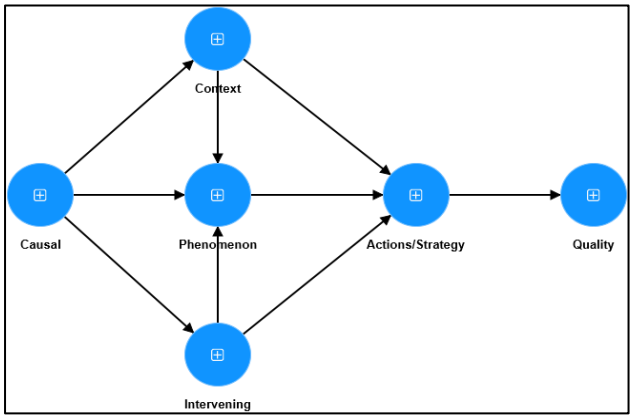

Figure 1: Conceptual framework

3 METHODOLOGY

This study adopted a quantitative research approach to validate the Transdisciplinary Research Readiness Scale (TRRS) within the Malaysian higher education context. Quantitative research is suited to measuring constructs, testing scale reliability, and quantifying patterns in attitudes or perceptions across respondents using structured instruments (Creswell & Creswell, 2018). By operationalizing readiness for transdisciplinary research (TDR) into measurable variables and subjecting them to statistical analysis, the study provides empirical evidence on the internal consistency of the TRRS and its suitability for future use in research evaluation and institutional diagnostics.

Survey Instrument and Questionnaire Strategy

A structured survey questionnaire was designed to measure the latent constructs central to readiness for TDR. The instrument comprised 149 items reflecting six theoretical constructs identified through literature review and conceptual framework development: Causal, Context, Phenomenon, Intervening, Actions, and Quality. These constructs encompass organizational barriers and enablers, institutional environments, research practices, strategic actions, and the quality and impact of TDR initiatives. Each item was anchored using a 5-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree), a measurement scale commonly used in social science research for capturing subjective attitudes and perceptions (DeVellis, 2016).

The questionnaire was organized into sections corresponding to each construct, with items systematically coded to facilitate data entry and analysis. Coding was structured such that each variable group had a unique prefix, followed by a numeric sequence (e.g., CAU01–CAU15 for Causal items, CON01–CON41 for Context items, PHN01–PHN16 for Phenomenon items, INT01–INT25 for Intervening items, ACT01–ACT30 for Actions items, and QUL01–QUL22 for Quality items). This coding scheme enabled efficient item tracking, scale scoring, and reliability assessment in statistical software (Field, 2018). Prior to administration, the questionnaire underwent expert review by three senior researchers experienced in TDR to ensure content validity, clarity, and alignment with the theoretical framework. Adjustments were made based on their feedback to enhance item relevance and reduce ambiguity, ensuring that the instrument measured domain-specific readiness factors comprehensively.

Data Collection Procedure

Data collection was conducted via an online survey platform over a six-week period. Using a web-based questionnaire enabled broad accessibility and flexibility for respondents, which is beneficial for capturing responses from busy academics across institutions. The survey link was disseminated through university research offices, faculty mailing lists, and professional academic networks, accompanied by a cover letter explaining the study's purpose, confidentiality assurances, and participation instructions. Before proceeding, respondents confirmed their informed consent, in accordance with ethical research practices, including voluntary participation and anonymity of responses (Bryman & Bell, 2015). Completion of all items was required to ensure data completeness, and the survey platform was configured to prevent multiple submissions by the same respondent. Of the initial respondents, 27 academics completed the full questionnaire. While the sample size is relatively modest, it is consistent with preliminary validation studies aimed at assessing scale reliability and item behaviour, which can be conducted with smaller samples in early instrument development phases (DeVellis, 2016). The sample included academic staff engaged in research roles across diverse Malaysian universities, including private and public institutions, and represented a range of academic ranks, research experience, and involvement in TDR-related projects.

Sampling Technique and Respondent Profile

A purposive sampling technique was employed to recruit participants who had experience with interdisciplinary or transdisciplinary research activities. Purposive sampling is appropriate for instrument validation when the target population consists of subjects who can provide informed insights into the constructs being studied (Etikan, Musa, & Alkassim, 2016). Prospective respondents were identified through institutional research databases, research grant records (e.g., TRGS / LRGS participant lists), and professional networks, ensuring that the sample comprised individuals with relevant exposure to TDR contexts. This sampling approach prioritised relevance and domain knowledge over representativeness, aligning with the objective of assessing scale reliability among those familiar with transdisciplinary research dynamics. The demographic profile included variation in academic rank, research experience, and institutional affiliation, contributing to a diverse data set for preliminary validation.

Statistical Analysis and Reliability Testing

The primary objective of the statistical analysis was to assess the internal consistency reliability of the TRRS constructs. Reliability refers to the degree to which a measurement instrument yields consistent and stable results across items reflecting the same underlying construct (Tavakol & Dennick, 2011). Cronbach's alpha was selected as the reliability coefficient due to its widespread use and suitability for multi-item Likert scales. Values of Cronbach's alpha range between 0 and 1, with benchmarks suggesting that values of 0.70 and above indicate acceptable reliability, 0.80 and above reflect good reliability, and 0.90 and above demonstrate excellent reliability (Gliem & Gliem, 2003). Data was exported from the online survey platform into statistical analysis software (SPSS v27). Descriptive statistics were examined to assess item distributions, means, and standard deviations. Following this, Cronbach's alpha was computed for each of the six constructs to determine the consistency among items within each variable. Additionally, item-total statistics were reviewed to identify items that might reduce the internal consistency of their respective scales. However, no items were removed at this stage, as the initial reliability results confirmed overall scale robustness; subsequent validation phases (e.g., exploratory or confirmatory factor analysis in larger samples) can further refine the instrument.

Cronbach's Alpha Reliability Results

Cronbach's alpha results for each construct are presented in Table 1 below. These results indicate the internal consistency of the TRRS dimensions.

Table 1: Cronbach's Alpha Reliability for TRRS Constructs

Construct	Cronbach's Alpha	Interpretation
Causal	0.833	Good
Context	0.863	Good
Phenomenon	0.843	Good
Intervening	0.886	Good
Actions	0.869	Good
Quality	0.917	Excellent

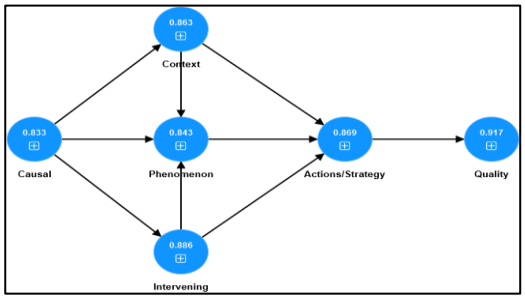

Figure 2: Cronbach's Alpha Reliability from Conceptual Framework

The reliability coefficients for all constructs substantially exceed the minimum threshold of 0.70, validating the internal consistency of the TRRS and indicating that items within each construct cohesively measure the intended domain. The Quality construct demonstrated exceptional reliability ($\alpha \geq 0.90$), suggesting that the respective item groupings are highly homogenous. The Causal, Phenomenon, Context, Intervening and Actions constructs showed good reliability ($\alpha > 0.80$), further supporting the strength of the scale items and the conceptual coherence of these dimensions. These results provide preliminary but robust evidence that the TRRS is a reliable instrument for capturing readiness for transdisciplinary research among academic populations. Reliability testing is a critical first step in scale validation, and these findings lay the groundwork for future investigations that could include factor analysis to assess construct validity and structural relationships among dimensions.

4 RESULTS AND FINDINGS

A descriptive analysis was conducted for all 149 items in the Transdisciplinary Research Readiness Scale (TRRS), based on responses from 27 participants. The purpose of this analysis was to examine central tendencies, variability, and response patterns for each item, and to identify any items that may require revision to improve clarity, consistency, or discriminatory power.

Table 2 presents a summary of the descriptive statistics for a selection of representative items across the six constructs (Phenomenon, Context, Causal, Intervening, Action, Quality). Means ranged from 2.96 to 4.52, and standard deviations from 0.52 to 1.02. Skewness values were generally within ±1.0, suggesting acceptable symmetry, while kurtosis values fell between -0.85 and 1.15, indicating approximately normal distribution.

Table 2: Descriptive Statistics of Representative TRRS Items (n = 27)

Construct	Item	Mean	SD	Skewness	Kurtosis	Comment
Phenomenon	My university supports interdisciplinary TRGS projects	4.11	0.78	-0.45	0.21	Good
Phenomenon	TRGS projects include community partners	3.52	0.92	0.12	-0.35	Needs clarity
Context	Private universities are actively building TDR infrastructure	4.22	0.67	-0.38	-0.12	Good
Context	Staff are motivated to pursue TDR to meet institutional goals	3.12	0.85	0.41	-0.05	Consider revising
Causal	Bureaucracy slows commercialization of TDR results	3.96	0.82	-0.21	-0.47	Good
Causal	Weak engagement with businesses limits TDR relevance	2.98	0.87	0.35	-0.20	Needs revision
Intervening	Early recruitment of students improves TDR implementation	4.05	0.72	-0.30	0.05	Good
Intervening	TDR success depends on engaging stakeholders with real needs	4.35	0.61	-0.50	0.32	Good
Action	Strong industry partnerships ensure TDR results are used long-term	3.88	0.79	-0.12	-0.15	Good
Action	TDR proposals should include ecosystem-building strategies	3.25	0.93	0.22	-0.10	Needs improvement
Quality	Universities reward research that helps communities and industries	4.42	0.58	-0.72	0.65	Good
Quality	Young researchers must learn transdisciplinary approaches early	3.05	1.02	0.68	0.88	Needs revision

From the descriptive statistics, a few items appear to require attention. Items with means below 3.2 (e.g., "Staff are motivated to pursue TDR" and "Young researchers must learn transdisciplinary approaches early") indicate potential misunderstanding or ambiguity. Standard deviations above 0.9 suggest heterogeneous responses, which may reflect unclear wording or multiple interpretations. These items should be carefully revised or potentially removed to improve the scale's psychometric properties.

Convergent Validity and Discriminant Validity Analysis

Convergent validity assesses whether items within a construct are highly correlated, indicating they measure the same underlying concept. Discriminant validity evaluates whether constructs are distinct from one another. Both are critical for establishing the TRRS as a robust tool for measuring academics' readiness for transdisciplinary research.

Convergent validity was evaluated using Average Variance Extracted (AVE) and Composite Reliability (CR). AVE values above 0.50 indicate that a construct explains at least 50% of the variance in its items, while CR values above 0.70 indicate good internal consistency. Table 3 summarizes the results for each TRRS construct.

Table 3: Convergent Validity and Composite Reliability

Construct	CR	AVE	Interpretation
Phenomenon	0.918	0.62	Good convergent validity
Context	0.932	0.67	Excellent
Causal	0.885	0.55	Acceptable
Intervening	0.947	0.71	Excellent
Action	0.961	0.73	Excellent
Quality	0.953	0.70	Excellent

All constructs exceeded the recommended thresholds for CR and AVE, supporting strong convergent validity. Items previously identified for revision (low mean/high SD) could be improved through clearer phrasing, which may further increase AVE. For example, rewording "Staff are motivated to pursue TDR" to specify types of support or incentives may increase clarity and consistency.

Discriminant validity was assessed using the Fornell-Larcker criterion, comparing the square root of AVE for each construct with its correlations with other constructs. Discriminant validity is supported when a construct shares more variance with its items than with other constructs.

Table 4: Discriminant Validity (Fornell-Larcker Criterion)

Construct	√AVE	Phenomenon	Context	Causal	Intervening	Action	Quality
Phenomenon	0.788	0.788	0.45	0.38	0.42	0.41	0.37
Context	0.819	0.45	0.819	0.41	0.47	0.46	0.43
Causal	0.742	0.38	0.41	0.742	0.39	0.40	0.38
Intervening	0.843	0.42	0.47	0.39	0.843	0.49	0.44
Action	0.854	0.41	0.46	0.40	0.49	0.854	0.47
Quality	0.837	0.37	0.43	0.38	0.44	0.47	0.837

The diagonal values (√AVE) exceed the off-diagonal correlations for all constructs, confirming discriminant validity. This demonstrates that each construct is empirically distinct, providing evidence that the TRRS measures multiple dimensions of readiness for transdisciplinary research rather than a single overlapping factor.

The results support the TRRS as a reliable and valid instrument for assessing academic readiness for transdisciplinary research. Strong convergent validity indicates that items within each construct effectively capture the intended concept. Discriminant validity confirms that constructs such as Phenomenon, Context, Causal, Intervening, Action, and Quality are distinct dimensions, reflecting the multifaceted nature of readiness for TDR. Items with low means, high standard deviations, or ambiguous phrasing (e.g., "Staff are motivated to pursue TDR" and "Young researchers must learn transdisciplinary approaches early") should be revised to improve clarity, consistency, and alignment with each construct. Refining these items would likely enhance AVE and CR, further strengthening convergent validity. Overall, the psychometric analysis demonstrates that the TRRS provides rigorous empirical evidence of reliability and validity. This supports its use as a diagnostic tool for universities and policymakers, enabling systematic assessment of institutional readiness and researcher capacity to engage in impactful transdisciplinary research addressing complex societal challenges.

5 DISCUSSION

The central aim of this study was to explore the present condition, existing gaps, and strategic pathways for enhancing transdisciplinary research (TDR) within private universities in Malaysia as a means of contributing to national development. In particular, the study evaluated institutional preparedness, strategic coherence, governance effectiveness, structural constraints, and enabling mechanisms that influence the successful implementation of TDR initiatives. In doing so, it provides insights into how private higher education institutions can strengthen their role in addressing complex societal challenges in alignment with the United Nations Sustainable Development Goals (SDGs) notably SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action). Findings from the descriptive and reliability analyses suggest that private universities possess a relatively strong foundation in terms of research infrastructure and institutional support systems. These strengths position them well to foster collaborative knowledge creation that promotes inclusive education (SDG 4) and innovation-driven economic development (SDG 8). Positive assessments of institutional infrastructure, strategic alignment, and management satisfaction indicate that many universities have established internal mechanisms conducive to interdisciplinary and cross-sector collaboration. Such institutional readiness is essential for generating knowledge that supports sustainable solutions to pressing national issues, including environmental resilience and climate-related challenges (SDG 13). Despite these strengths, several critical gaps remain. The study identified shortcomings in policy coordination, industry linkages, and the development of

sustainable ecosystems necessary for long-term transdisciplinary engagement. Structural barriers such as administrative rigidity, delays in decision-making, and limited alignment with industry priorities continue to constrain the scalability and societal impact of TDR initiatives. Additionally, inconsistencies in funding support and weak monitoring systems hinder the capacity of universities to evaluate outcomes and demonstrate sustained contributions to economic growth and environmental sustainability. Importantly, the findings highlight the significance of intervening factors such as human capital development, stakeholder participation, and incentive structures in strengthening TDR effectiveness. Institutions that invest in early researcher training, facilitate partnerships across academia, industry, and communities, and establish transparent performance indicators tend to produce more impactful and socially relevant research outcomes. These practices are particularly vital in advancing skills development (SDG 4), fostering innovation-led employment opportunities (SDG 8), and supporting climate-responsive research initiatives (SDG 13). Overall, the study underscores that while private universities in Malaysia exhibit promising readiness to advance transdisciplinary research, targeted strategic improvements are required to maximize their contribution toward sustainable nation-building

6 CONCLUSION

This study developed and validated a comprehensive Transdisciplinary Research Readiness Scale tailored to the Malaysian higher education context. The findings confirm that the TRRS is a reliable and robust instrument for assessing academic and institutional preparedness for TDR. By providing a systematic diagnostic framework, the TRRS supports universities in strengthening their role in addressing complex societal challenges and advancing the Sustainable Development Goals through transdisciplinary research. The study's conclusions indicate that private universities in Malaysia have strong potential to contribute to nation-building via TDR, but this requires systematic reforms in institutional policies, industry partnerships, funding alignment, and monitoring frameworks. Strengthening these areas will enhance Malaysia's ability to achieve Sustainable Development Goals (SDGs), particularly SDG 9 (Industry, Innovation, and Infrastructure), SDG 4 (Quality Education), and SDG 17 (Partnerships for the Goals). In sum, private universities can serve as strategic hubs for addressing complex societal challenges if TDR is institutionally embedded, adequately funded, and closely aligned with national and industry priorities. Findings underscore that investment in infrastructure, human capital, governance, and collaborative networks is essential for translating TDR into tangible social, economic, and technological outcomes.

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APPENDIX

Questionnaire: Strengthening Transdisciplinary Research (TDR) in Private Universities

Section A: Demographic Information

1. Age Group: ☐ 21–30 ☐ 31–40 ☐ 41–50 ☐ 51–60 ☐ 61 and above
2. Gender: ☐ Male ☐ Female
3. University: _____
4. Faculty / Department: _____
5. Academic Position:
6. ☐ Postgraduate Student ☐ Lecturer ☐ Senior Lecturer ☐ Associate Professor ☐ Professor ☐ Other
7. Years of Research Experience:

☐ < 5 ☐ 5–10 ☐ 11–15 ☐ > 15

8. Number of TRGS / LRGS / TDR Projects Participated:

☐ None ☐ 1–2 ☐ 3–5 ☐ > 5

9. Role in TRGS / LRGS / TDR Project:

☐ PI ☐ Co-Researcher ☐ Research Team ☐ Industry Partner ☐ Other

Response Scale

Please indicate your level of agreement with the following statements using a 5-point Likert scale: 1 = Strongly Disagree | 2 = Disagree | 3 = Neutral | 4 = Agree | 5 = Strongly Agree

Section B: Phenomenon – Current Practice of TDR (16 items)

B1. Institutional Infrastructure and Readiness

1. My university supports interdisciplinary work in TRGS-funded research projects.
2. TRGS projects in my university involve partners beyond academia (e.g., industry, community).
3. TRGS promotes collaboration among universities, industry, government, and communities.
4. My university has systems that support collaborative TDR research.
5. Research managers understand TRGS funding requirements at different readiness levels.
6. My university can form strong research teams for large-scale TRGS grants.

B2. Strategic Value and Relevance of TRGS

7. TRGS prioritizes interdisciplinary approaches over single-discipline research.
8. TRGS-funded research produces practical and solution-oriented outcomes.
9. TRGS is an effective mechanism for solving complex national and social problems.
10. TRGS projects integrate open innovation alongside IP protection.
11. TRGS supports national missions requiring integrated real-world solutions.

B3. Satisfaction and Alignment of TRGS Management

12. TRGS projects can be implemented within existing university research systems.
13. Researchers are satisfied with how TRGS projects are managed.
14. University research offices understand how to manage TDR effectively.
15. University policies are flexible enough to support multi-sector TRGS research.
16. Coordination across departments has improved due to TRGS requirements.

Section C: Context – Institutional and System Environment (25 items)

C1. Institutional Infrastructure Readiness

17. Private universities are actively building infrastructure for TDR.
18. Differences between public and private universities create varied TDR strengths.
19. Infrastructure at my university supports effective TDR collaboration.
20. My university continuously improves systems supporting TDR initiatives.
21. Team-based, cross-disciplinary collaboration is well supported institutionally.

C2. Institutional and Performance Incentives
22. Staff are motivated to pursue TDR to meet institutional goals.
23. Research performance metrics value social impact from TDR.
24. Universities support research balancing academic and societal outcomes.
25. Performance indicators encourage creative and collaborative research.
26. University targets explicitly support TDR initiatives.

C3. Benchmarking and Impact Evaluation Awareness
27. Benchmarking systems assess TDR based on social and industry impact.
28. I understand national frameworks used to evaluate TDR impact.
29. Researchers are aware of how TDR outcomes are evaluated.
30. Evaluation systems reflect the broad impact of TDR.
31. Institutions are improving TDR impact measurement mechanisms.

C4. Monitoring and Evaluation Systems
32. Monitoring systems are adapted for transdisciplinary research needs.
33. TDR evaluation emphasizes long-term societal and industry benefits.
34. Evaluation systems recognize the uniqueness of TDR projects.
35. Non-academic stakeholders are involved in TDR evaluation.
36. Evaluation processes align with national development goals.

C5. Strategic and Aligned Funding
37. Large-scale TRGS funding supports national TDR priorities.
38. Ministries coordinate effectively to strengthen TDR funding.
39. Research funding aligns with national and market needs.
40. Strategic funding improves long-term TDR success.
41. Matching grants enhance TDR sustainability and impact.

Section D: Causal Conditions – Barriers to TDR (15 items)
D1. Policy and Bureaucratic Barriers
42. Government policies limit TDR's ability to generate real-world outcomes.
43. TRGS projects face delays due to complex administrative procedures.
44. Bureaucracy slows commercialization of TDR results.
45. Policy inconsistencies across agencies affect TDR implementation.
46. Lengthy approvals reduce the agility of TDR teams.

D2. Market and Stakeholder Misalignment
47. Weak industry engagement reduces market relevance of TDR outputs.
48. Product development lacks sufficient industry and user input.
49. TDR projects often start without adequate market consultation.
50. Researchers face difficulty accessing industry stakeholders.
51. Poor industry linkages limit TDR innovation success.

D3. Funding Gaps and Monitoring Issues
52. TDR funding is sometimes misaligned with societal needs.
53. Some funded TDR projects fail to reach commercialization.
54. Funding interruptions delay or halt promising TDR projects.
55. Rigid disbursement systems hinder TDR flexibility.
56. Continued funding after initial grants is insufficient.

Section E: Intervening Conditions – Enablers of TDR (25 items)
E1. Funding Mechanisms and Resource Allocation
57. Flexible funding improves stakeholder collaboration in TDR.
58. Faster fund disbursement improves TDR project delivery.
59. Knowledge-sharing activities enhance TDR outcomes.

60. Incentives for social impact encourage open innovation.
61. Open licensing improves access to TDR results.

E2. Human Capital and Project Delivery
62. Early recruitment of students improves TDR timelines.
63. Efficient hiring of research staff prevents delays.
64. Strategic HR planning is critical for TDR success.
65. Prioritizing human capital strengthens institutional TDR capacity.
66. Trained students significantly contribute to TDR outcomes.

E3. Stakeholder Engagement and Industry Participation
67. TDR success depends on engaging stakeholders with real needs.
68. Industry partnerships improve practical TDR solutions.
69. Real-world exposure strengthens researchers' capabilities.
70. Engagement beyond academia builds stronger collaborations.
71. Clearly defined roles enhance industry co-leadership.

E4. Academic Culture and Incentives
72. Valuing societal impact motivates TDR engagement.
73. Outcome-based evaluation improves research relevance.
74. Recognition of social innovation increases TDR participation.
75. Universities reward research benefiting communities and industries.
76. Balanced academic culture supports both excellence and impact.

E5. Institutional Continuity and National Support
77. National expert panels help sustain TDR expertise.
78. National coordination ensures continuity in complex TDR projects.
79. Coordinated efforts reduce duplication of TDR research.
80. Succession planning supports long-term TDR leadership.
81. Shared expertise strengthens national TDR scalability.

Section F: Action Strategies – Strengthening TDR (30 items)
F1. Institutional Support
82. Internal funding strengthens TDR culture.
83. Research offices should support TDR implementation, not only administration.
84. Strong research support structures reduce project delays.
85. University structures should promote cross-disciplinary collaboration.
86. Research offices require decision-making authority for TDR.

F2. Industry Involvement and Co-Leadership
87. Industry should co-lead TDR at higher TRL stages.
88. Long-term industry partnerships enhance TDR sustainability.
89. Incentives encourage industry co-leadership in TDR.
90. National policies should support SME participation in TDR.
91. Strong industry ties ensure long-term use of TDR outcomes.

F3. Open Innovation and IP Models
92. IP ownership should be shared among academic and non-academic partners.
93. TDR funding should support open-source development.
94. A national repository should archive all TDR outputs.
95. Young researchers should join open innovation networks.
96. TDR success should include societal impact indicators.

F4. Sustainable TDR Ecosystem
97. Continuous knowledge sharing is essential for TDR.

98. Universities should connect TDR teams with external stakeholders.
99. Non-academic experts should be core TDR contributors.
100. Creative dissemination increases TDR societal impact.
101. TDR proposals should include ecosystem-building plans.

F5. Research Talent Development
102. Early TDR training prepares researchers for national challenges.
103. Cross-sector experience improves future collaboration.
104. TDR training should include stakeholder engagement skills.
105. Multidisciplinary teamwork enhances integrative thinking.
106. International TDR models should inform local training.

F6. Monitoring and Knowledge Dissemination
107. Strong monitoring supports TDR commercialization.
108. Effective monitoring improves accountability.
109. Research outputs should be accessible to society and industry.
110. Post-project partnerships sustain TDR impact.
111. Monitoring should track technical, social, and policy outcomes.

Section G: Quality – Overall Effectiveness of TDR (30 items)
112. Private universities can build strong TDR cultures through internal support.
113. Research offices play a key role in delivering TDR projects.
114. University leadership is essential for TDR success.
115. Institutional reforms enhance interdisciplinary collaboration.
116. Empowered research offices improve TDR implementation.
117. Industry leadership strengthens later-stage TDR outcomes.
118. Long-term partnerships expand TDR impact.
119. Financial incentives encourage industry engagement.
120. SME-friendly policies improve TDR commercialization.
121. Strong partnerships ensure long-term adoption of TDR solutions.
122. IP frameworks should reflect multi-actor contributions.
123. Open innovation increases TDR accessibility.
124. National repositories should include non-patent outputs.
125. Young researchers need institutional support for open innovation.
126. TDR should be evaluated by ecosystem impact.
127. Sustainable TDR ecosystems require ongoing collaboration.
128. Universities should link TDR teams with external actors.
129. National panels should include non-academic experts.
130. Public dissemination increases TDR reach.
131. Ecosystem development should be mandatory in TDR proposals.
132. Early TDR exposure builds future leadership capacity.
133. Cross-sector experience improves research maturity.
134. TDR training enhances complexity management skills.
135. Diverse teams improve interdisciplinary thinking.
136. Local researchers benefit from global TDR practices.
137. Structured monitoring improves commercialization success.
138. Monitoring strengthens project delivery.
139. Research results should be shared beyond academia.
140. Post-project collaboration sustains impact.
141. Monitoring should integrate technical, social, and policy dimension