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Paving the future: the role of responsible artificial intelligence, hybrid intelligence and leaders' symbolisation in leveraging breakthrough innovations

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Abstract: Artificial intelligence (AI) integration within businesses has significantly altered human resource management techniques. Despite AI's expected advantages, employees harbour legitimate concerns and challenges. However, a notable dearth of discourse surrounding responsible AI exists. To bridge this gap, this study draws on signalling theory (ST) and social exchange theory (SET) to present a model outlining responsible AI's (RAI) effect on employees' breakthrough innovation engagement. Using 344 employees' valid survey responses from Pakistan's high-tech sector, Hayes Process Macro was employed to examine the moderated-mediation model. The results illustrate RAI enhances breakthrough innovation engagement through hybrid intelligence utilisation. Moreover, the findings showed that leaders' RAI symbolisation strengthens the relationship between RAI, hybrid intelligence use, and breakthrough innovation engagement. By demonstrating the influential role of RAI in breakthrough innovations, this research offers critical insights for both theory and practice.

Keywords: responsible artificial intelligence; RAI; breakthrough innovation engagement; hybrid intelligence; leaders' RAI symbolisation.

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1 Introduction

The fourth industrial revolution, commonly known as Industry 4.0, signifies the rapid incorporation of advanced smart technologies into conventional manufacturing and industrial processes (Kistyanto et al., 2022). The swift advancement of technology has led to significant changes in the realm of human resource management for organisations that adopt artificial intelligence (AI), aiming to foster employee engagement in breakthrough innovations (Rachinger et al., 2018; Tariq et al., 2024b). According to recent reports, AI applications will not only affect business orientations but also significantly contribute to global revenue, which is expected to reach \$118.6 billion by 2025 (Chowdhury et al., 2023). AI is a sophisticated technology that seeks to enhance human intelligence (Glikson and Woolley, 2020; Tariq et al., 2024b). Nevertheless, significant challenges and legitimate concerns among the workforce outweigh the expected advantages of AI (Ransbotham et al., 2017). The concerns about AI-induced job automation and the ethical challenges that accompany its unpredictable side effects are considerable stressors for employees (Aker et al., 2021; Floridi and Cowls, 2022). However, discussions around AI's responsible approach, emphasising sustainable usage, remain scarce (Bujold et al., 2023; Mikalef et al., 2022). Thus, it is crucial to investigate the influence of responsible AI (RAI) on employee behaviour, particularly in high-tech firms, amidst the emerging trends of breakthrough innovations.

Responsible AI (RAI) reflects a collection of principles aimed to ensure a transparent, ethical, and accountable use of AI aligning with social standards, organisational values, and users' expectations (Floridi and Cowls, 2022; Floridi et al., 2018; Tariq et al., 2024a; Wang et al., 2023). Similarly, with understanding of the AI ethical risk, RAI is often developed guided by required bioethical principles (Wang et al., 2023). Recent research has also stressed the importance of employees' innovative engagement in combination with the implementation of technological solutions, including RAI (Tariq et al., 2024b). Accordingly, RAI integration elevates employees' cognitive engagement and facilitates the market performance of organisations (Kumar et al., 2021). Consequently, there has been much emphasis on outlining business strategies that facilitate the integration of RAI into business practices. Despite this, current literature on RAI mainly consists of conceptual and experimental studies, lacking broad applicability across varying

organisational contexts (Bujold et al., 2023; Mikalef et al., 2022). Additionally, there are few theoretically grounded empirical studies exploring the relationship between RAI and employee engagement, particularly concerning breakthrough innovation engagement (BIE). Thus, the present research fills the knowledge gap by investigating (RQ1) how RAI influences breakthrough innovation engagement among high-tech employees?

Responsible AI (RAI) encourages an organisational culture that fosters ongoing innovation and effective collaboration between humans and machines. Prior research illustrates that effective AI incorporation not only improves business operations but also results in employees' superhuman performance when AI and human capabilities are combined within a hybrid intelligence framework (Chen et al., 2022). Under this hybrid intelligence paradigm, people make decisions by combining their own intuition and empathy with AI's predictive abilities (Frantz, 2003; Tariq et al., 2024b). Hybrid intelligence utilisation (HIU) synthesises employees' intuitive insights with analytical reasoning and individual learning (Wilkins, 2020), empowering them to identify opportunities for innovation. Moreover, HIU cultivates employees' psychological ownership and elevates their commitment toward organisational goals. Recent research also demonstrated HIU's positive role in enhancing employees' self-extension and engagement in breakthrough innovation initiatives within high-tech firms (Abbas et al., 2022). Likewise, AI's responsible deployment nurtures a collaborative environment that inspires the effective utilisation of hybrid intelligence among employees (Tariq et al., 2024b), thereby improving their analytical capabilities and nurturing a greater sense of engagement and commitment. Thus, HIU serves as a mediator between RAI and employee engagement in innovative breakthroughs.

Furthermore, a leader's influence is crucial for the successful adoption of AI within businesses. As such, the leadership phenomena encompass a person's capacity to influence other people, i.e., followers – in order to attain organisational goals (Mahmood et al., 2019). In addition, scholars call the role of internal resources for developing distinctive (i.e., AI implementation) and hard-to-imitate capabilities (i.e., leadership) in turbulent, technology-driven business environments (Chowdhury et al., 2023; Mikalef and Gupta, 2021). However, a traditional managerial skill that focuses on efficiency improvement alone does not fit the context (Dhamija et al., 2023). Similarly, leaders' RAI symbolisation behaviours, demonstrating their adoption and inclination towards RAI by engaging in RAI-related behaviours and/or displaying objects that reflect their affinity for RAI, can effectively manage employee relationships in RAI-driven environments (Tariq et al., 2024a). Thus, the present research also attempts to expand the understanding of leadership and RAI by exploring (RQ2) whether leaders' RAI symbolisation moderates the relationships between RAI, HIU, and BIE among high-tech employees.

The present research also aims to contribute in several ways. First, it is amongst the few studies to assess the impact of RAI on BIE in high-tech organisations. Hence, by empirically examining these associations this study answers the calls for research regarding RAI's influence on employee behaviours (Bujold et al., 2023; Mikalef et al., 2022) but also contributes to the knowledge base on drivers of BIE in high-tech firms. Second, it adds to the scarce literature on RAI, HIU, and BIE association in Pakistan's context (Abbas et al., 2022; Tariq et al., 2024b). Besides the scarcity of work, Pakistan's distinct cultural values and high collectivism score (Hofstede, 1984) may help explain this incongruence since reciprocal expectations of being cared about on the part of organisations, leaders, and employees exist in such a culture. Thus, employees within these cultures are significantly influenced by organisations' ethical AI incorporation and

leaders' RAI symbolisation, thereby providing motivation and satisfaction to employees, fundamentals imperative to BIE (Euchner, 2012). Third, it contributes methodology and literature through a holistic perspective of investigating the mediation of the hybrid intelligence approach with the moderation of leaders' RAI symbolisation in the nexus of RAI and BIE. Therefore, drawing on signalling theory (ST) (He et al., 2023) and social exchange theory (SET) (Homans, 1958), this study aims to fill the aforementioned gaps in the literature based on the high-tech sector of Pakistan.

The article is organised as follows. Section 2 formulates hypotheses after reviewing the literature. Sections 3 and 4 describe methods followed by analysis of data and results. Finally, sections 5 to 8 explicate the implications and limitations and outline future research directions.

2 Theoretical foundations and literature review

2.1 *Signalling theory and social exchange theory*

ST posits that actions and behaviours serve as indicators of intentions and preferences (He et al., 2023). Signalling allows individuals to overcome the information asymmetry between themselves and others, thereby facilitating a more effective comprehension of intentions. Management research at the organisational, group and individual levels has extensively used ST (Mikalef and Gupta, 2021). In particular, it has helped to explain how leadership actions and characteristics act as signifiers that foster employee attitudes and behaviours (Benner and Tushman, 2003). Leaders may convey signals implicitly through social learning processes (He et al., 2023) or explicitly through sensemaking activities, as suggested by ST. Likewise, with AI's ongoing progress, scholars are increasingly utilising ST to examine the interactions between AI systems and the workforce. For instance, (Mirbabaie et al., 2021) conceptualise features of virtual assistants (such as artificiality or intelligence) as signals that influence users' perceptions. Similarly, (Wang et al., 2023) claim that commitment to bioethical principles in deploying AI may suggest responsible usage of AI and induction of desirable employee behaviours toward responsible AI (RAI). Therefore, the integration of RAI in high-tech firms conveys a commitment to responsible AI and helps form positive attitudes and intentions toward its use, thereby promoting HIU.

Likewise, SET's foundation is consistent with this notion by asserting that when organisations demonstrate supportive conduct toward their employees, an obligation emerges from such exchange (Ilies et al., 2007). Subsequently, employees exhibit a reciprocal response by demonstrating a desire to perform effectively and maintain a positive attitude (Cropanzano and Mitchell, 2005). Moreover, SET suggests employer and employee interactions to include both economic and psychological exchanges (Cropanzano and Mitchell, 2005). For high-tech professionals, it can be manifested in the development of RAI systems, reducing employee anxiety and increasing trust in these systems, which ultimately enhances cooperation, positive intentions, and employee task performance. Thus, RAI incorporation can signal employees regarding the supporting nature of these technologies and result in employee reciprocation with enhanced HIU and BIE. Likewise, consolidating leaders' RAI symbolisation as a moderator helps employees comprehend the essence of RAI technologies and strengthens the adoption, execution, and advancement of RAI-driven solutions. In other words, using the signalling and social

exchange theories provides an appropriate theoretical context to examine whether, how, and when RAI influences BIE in high-tech firms.

2.2 *Hypothesis development*

2.2.1 *Responsible artificial intelligence and breakthrough innovation engagement*

By adopting AI, enterprises can organise and utilise resources, people, and prior dispersed strengths. Additionally, AI equips organisations to refine and optimise their operational methodologies through the utilisation of sophisticated, intelligent tools and algorithms (Arslan et al., 2022). Similarly, AI technologies enable organisations to streamline processes and procedural workflows (Benner and Tushman, 2003) by delegating routine tasks to AI, thereby enhancing the efficiency of tasks requiring higher levels of skill. Moreover, certain studies within this domain demonstrate AI's positive impact on employee engagement, performance, and productivity. However, other researchers argue that the integration of AI heightens employee apprehension and concern regarding job displacement, leading to adverse employee behaviours such as scepticism, turnover intentions, and organisational misconduct (Khaliq et al., 2022; Zhao et al., 2023). Collectively, the existing literature extensively portrays AI as exerting a nuanced influence on employee outcomes.

Conversely, RAI, rooted in fundamental bioethical principles such as beneficence, non-maleficence, autonomy, justice, and explainability (Floridi and Cowsls, 2022; Floridi et al., 2018; Wang et al., 2023), leverages the capabilities of AI to effectively enhance both business operations and societal well-being. According to Peters et al. (2020), RAI is delineated as a set of principles aimed at:

- 1 guiding AI systems to generate economic value through high-tech service delivery in a responsible manner
- 2 ethically orchestrating the competencies of AI and high-tech experts to achieve positive outcomes for diverse stakeholder groups
- 3 utilising AI to promote fairness, social inclusion, and sustainability within high-tech environments.

Prior investigations suggest that the thoughtful design of AI systems fosters user trust and ease in engaging with these technologies (Tariq et al., 2024a; Wang et al., 2023), which is essential for cultivating employees' breakthrough innovation engagement (BIE). Furthermore, by diminishing uncertainty and strengthening employees' trust, RAI technologies enable employees to effectively employ AI-generated insights (Kumar et al., 2021). Hence, RAI, reflecting ethically oriented AI applications within a supportive work environment, enhances employees' concentration and decision-making competencies (Tariq et al., 2024a), which subsequently improves their engagement in innovative breakthroughs. Thus, it is hypothesised:

- Hypothesis 1 Responsible artificial intelligence has a significant positive impact on breakthrough innovation engagement.

2.2.2 *Responsible artificial intelligence and hybrid intelligence use*

RAI functions as a fundamental element for organisations to progress, promoting ethically-informed business strategies that highlight a dedication to proactive initiatives. Prior research highlights that the incorporation of RAI into operational frameworks significantly boosts employee productivity, thus optimising organisational processes and workflows (Chen et al., 2023). Moreover, recent studies imply a positive response to this approach in the sense that it fulfils user expectations, societal norms, and organisational values. For instance, (Peters et al., 2020) demonstrate that AI-enabled systems designed with autonomy principles improve customer engagement and empower employees with better decision-making. Additionally, RAI integrates the individual and the society in the professional sphere, and the delivery of ethical and beneficial services to society (Tariq et al., 2024b; Verma and Singh, 2022) signifies an environment conducive to fostering positive AI interactions at workplace.

Similarly, the RAI notion seeks to align AI systems with the key bioethical principles, particularly with notable regard to employee autonomy (Wang et al., 2023). Additionally, prior research has shown that employees with greater AI-enabled job autonomy are more likely to produce innovative ideas resulting from greater work process control and enhanced conscious decisions based on AI-driven insights, elements necessary in promoting HIU. Additionally, employees' intrinsic needs for efficacy and effectiveness motivation satisfaction via such autonomy are closely linked to their psychological ownership formation (Rich et al., 2010). Previous studies suggest that this psychological state enables employees to fulfil their need for belongingness and contribution to the organisation through reciprocal actions (Ng and Feldman, 2012). Therefore, based on ST and SET, the implementation of RAI in high-tech firms is expected to encourage employees to invest in a hybrid intelligence approach to innovation and productivity. Therefore, the study hypothesises:

Hypothesis 2 Responsible artificial intelligence has a significant positive impact on hybrid intelligence use.

2.2.3 *Hybrid intelligence use and breakthrough innovation engagement*

In the realm of human resource management literature, there exists a dearth of research on hybrid intelligence. Nevertheless, recent research has initiated an investigation into this emerging field aiming to elucidate the conceptual relationship between hybrid intelligence and breakthrough innovation engagement (BIE). These investigations underscore that the synergy between human intellect and artificial intelligence cultivates innovation, a sense of psychological ownership, and heightened employee engagement in innovative endeavours (Abbas et al., 2022). Hybrid intelligence (HI), characterised by the integration of human and machine intellect, is not about replacing human cognitive abilities but rather complementing them to accomplish complex tasks (Akata et al., 2020).

This synergistic approach enables exceptional levels of performance in duties that necessitate the most advanced human intellect (Abbas et al., 2022). Moreover, research emphasises the importance of employee engagement, which is more highly predictive of success than employee commitment, satisfaction, and job involvement (Rich et al., 2010). Engagement is especially important for breakthrough innovation initiatives, as it is imperative to demonstrate commitment in order to envision and influence the future

(Euchner, 2012). Considering the holistic integration of human and machine cognition within the hybrid intelligence framework, which enhances processes, knowledge generation, psychological ownership, and employee productivity, it is plausible to expect a significant impact on breakthrough innovation engagement. Therefore, it is hypothesised:

Hypothesis 3 Hybrid intelligence use has a positive impact on breakthrough innovation engagement.

2.2.4 The mediating role of hybrid intelligence use

Hybrid intelligence strengthens psychological contracts, acceptance, and trustworthiness; as employee commitment is posed to be strong in the future, they have a part in (Abbas et al., 2022). In addition, the hybrid intelligence approach enhances the complementary synthesis of employees' intuition and analysis (Frantz, 2003) and individual learning (Wilkens, 2020), enabling them to spot innovation opportunities. Similarly, businesses gain competitive advantages from 'human-machine collaboration' advances and employees' integrated competencies that enable productive human-computer interaction (Wilson and Daugherty, 2018). In high-tech companies, digital innovations drive employee engagement that transforms employee interaction (Jesuthasan, 2017), such as RAI, capitalising bio-ethically driven AI integrated work on the specialisation of analytical approaches, such as systematic information collecting for reasoning and logical deliberation, so employees spend valuable time building creative innovations from their knowledge (Dwivedi et al., 2021; Lin et al., 2020).

Hybrid intelligence enables learning to scan material, merging knowledge from various disciplines and motivation toward learning (Vrontis et al., 2022). Moreover, the hybrid intelligence approach allows the highest performance by combining human and machine intelligence (Ostheimer et al., 2021). Hybrid intelligence promotes psychological ownership that stimulates employee engagement (Dellermann et al., 2019). Recent work confirms hybrid intelligence influences self-extension and fosters employees' BIE (Abbas et al., 2022). Also, studies drawing on SET noted that the opportunity to learn using new technologies diminishes turnover intentions and skill obsolescence, consequently influencing high-tech professionals' commitment to innovation (Harden et al., 2018). Similarly, since ethical AI implementation offers improved job focus, decision-making, and data processing for creativity through employee knowledge, a hybrid intelligence approach fosters innovation, psychological ownership, and employee engagement in innovative breakthroughs. Thus, the study hypothesises the following:

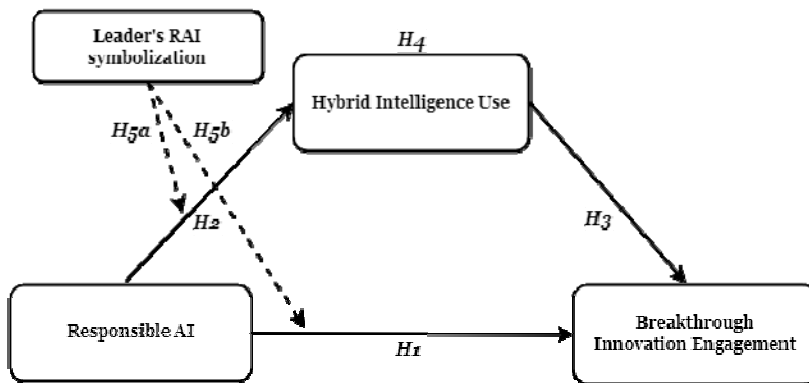
Hypothesis 4 Hybrid intelligence use mediates the positive relationship between responsible artificial intelligence and breakthrough innovation engagement.

2.2.5 The moderating role of leaders' RAI symbolisation

Advancements in technology are profoundly impacting humanity as robots increasingly play significant roles in areas of organisational and economic spheres (Arslan et al., 2022; Coupe, 2019). In the contemporary landscape, AI enables businesses to revamp their processes and procedures by leveraging new intelligent tools and algorithms

(Verganti et al., 2020). Furthermore, fostering a culture of ‘human-machine partnership’ and nurturing workers’ ‘fusion abilities’ yield substantial benefits for organisations (Wilson and Daugherty, 2018). As a result, AI is a fundamental component of the expansion, optimisation, and operational adaptability of business processes (Kelly et al., 2019; Wang et al., 2022). Furthermore, the integration of AI with businesses is also dependent on leadership (Tariq et al., 2024a, 2024b; Wijayati et al., 2022). However, more research is needed that examines the extent to which individual differences in leadership moderate technology adoption rather than only their direct effects (Bhatt, 2022). According to Hambrick and Mason (1984), organisational leadership is the body of a company’s ethos, whereby it has the capacity to motivate others, primarily followers, to achieve company objectives (Mahmood et al., 2019). Likewise, the work environment is significantly influenced by leadership dynamics, which also affect the way in which employees perceive their roles and responsibilities (Azim et al., 2019; Tariq et al., 2024a).

Figure 1 Conceptual framework



Recent research points to a growing trend wherein leaders are increasingly demonstrating behaviours that reflect their acceptance and support of AI technologies (He et al., 2023). Additionally, the characteristics and actions of leaders are powerful signals that have the ability to influence how employees think of themselves, their work, and their co-workers (Azim et al., 2019). Consequently, leaders’ responsible AI symbolisation (LRAIS) promotes and supports employees’ alignment with AI technologies (Tariq et al., 2024a), thereby increasing their internal motivation, self-assurance, and engagement levels with their tasks. LRAIS effectively engages individuals in creative endeavours within an RAI-infused environment, which also affects their psychological disposition (Azim et al., 2019; Matsunaga, 2022). Through visible support and acceptance towards RAI, leaders could not only inspire their followers to embrace AI but also create a shared vision (Tariq et al., 2024a, 2024b). Similarly, by doing so, leaders elevate employees’ empowerment within RAI settings, which leads to higher levels of HIU and employees’ BIE within high-tech enterprises. Therefore, the following hypotheses are stated:

Hypothesis 5a Leaders’ RAI symbolisation moderates the relationship between responsible artificial intelligence and hybrid intelligence use.

Hypothesis 5b Leaders' RAI symbolisation moderates the relationship between responsible artificial intelligence and breakthrough innovation engagement.

3 Research methodology

3.1 Sampling and data collection

This quantitative research used a non-probability sampling technique with a purposive sampling approach, considering consistent with prior studies research (Tariq et al., 2024b; Wijayati et al., 2022). The technology-intensive sector was chosen for data collection, as previous researchers (Abbas et al., 2022; Kamuriwo et al., 2017) deemed it suitable. Specifically, the present study respondents were employees associated with research and development within innovation-oriented companies (Silva et al., 2017), aiming for competitive advantages with workflow systems designed to involve AI tools. Data was collected from a variety of high-tech industries and demographically varied organisations in metropolitan cities of Pakistan, such as Islamabad, Lahore, and Karachi, thereby increasing the external validity of findings (Fariss and Jones, 2018). Moreover, purposive sampling was used to provide research objectives and respondent confidentiality, and the survey questionnaire was self-administered for data collection.

Questionnaire statements were basic and clear; each variable was introduced clearly, and voluntary participation with flexible response time was provided for reducing any biases (Tariq et al., 2024b; Toepoel and Schonlau, 2017). Following Roscoe (1975) rule of thumb, i.e., most research requires sample sizes of 30–500 (Sekaran and Bougie, 2016), this study distributed 700 questionnaires in two lags. In the first round, 608 were received back, while in the second round, only 520 were returned. Moreover, the matched survey comprised 422. Similarly, Wijayati et al. (2022) recommend that employees of target research institutions with at least one year of affiliation and above to constitute an adequate research sample. Thus, the study deemed responses of individuals with less than one year of experience in current organisations inappropriate. As a result, the present study removed 78 responses for being unsuitable (i.e., incorrect, inappropriate, outlined, and missing values), and 344 questionnaires were considered eligible for further analysis with an acceptable response rate of (344/700) of 49%. As the final number of useable survey responses corresponds to the accepted range of 300–500 recommended by Hair et al. (1998) for structural equation modelling (SEM), thus cause and effect relationships estimation was performed on Smart PLS 4 using the PLS-SEM technique.

PLS-SEM is a widely recognised approach utilised in business research for identifying complicated causal relationships (Gudergan et al., 2008; Tariq et al., 2024a). In our research study, 63% of the participants are men. As their highest qualification, the majority of responders (41.3%) possessed an MS or MPHILL degree. Just 24% of them work in the marketing departments of high-tech corporations, while the majority (76%) are in the R&D departments. Lastly, the average age of our participants was 35.1%, or between 29 and 32 years old. The majority of respondents spent three years in organisations.

3.2 *Measures*

This study used measures from prior studies and divided the survey questionnaire into two segments: the first segment consisted of respondents' demographics, i.e., gender, age, education, industry, and tenure in the organisation. The second segment examined study variables. As a result, consulting industry and AI experts conducted the pretest to determine the content validity of the complete set of questionnaires. This study examined RAI consisting of five components utilising the verified scales from the work of (Wang et al., 2023). These components contain beneficence (BEN), autonomy (AUT), justice (JUST), non-maleficence (N-MAL), and explainability (EXP). HIU was operationalised with four items adapted from the work of (Abbas et al., 2022). BIE was measured with five items taken from the study of (Abbas et al., 2022). Leader's RAI symbolisation was measured with a six-item scale developed by (He et al., 2023). The items of study variables were reported on a 5-point Likert scale (1 = strongly disagree and 5 = strongly agree), and respondents indicated the level of their disagreement or agreement with each statement (Sekaran and Bougie, 2016).

3.3 *Data analysis method and procedures*

This section presents descriptive statistics on reliability and validity and hypothesis testing results of the study. The results are based on the data collected from employees of high-tech organisations. Moreover, to examine the research framework and hypotheses, we employed structural equation modelling (SEM) for data analysis. Since the current research involved several observed variables that measure an unobserved construct and our aim involved the analysis of structural relationships between variables, thus SEM was deemed appropriate (Abbas et al., 2022; Verma and Singh, 2022). Accordingly, a two-step method to analyse the study data was employed. First of all, we checked the reliability and validity of our data by examining the measurement model with SmartPLS-4. This analytical process consisted of three sequential stages: method bias investigation, confirmatory factor analysis (CFA), and model evaluation. Third, we used the Hayes Process Macro in SPSS V25 to test the direct, mediating, and moderated-mediation effects.

4 **Results**

4.1 *Common method bias*

We used Harman's single-factor test for evaluating common method bias (CMB) in the current investigation. The findings showed that no single component accounted for more than 50% of the variance; specifically, the principal factor accounted for only 38.43% of the total variance. Consequently, the analysis concluded that CMB did not pose a significant concern. Furthermore, the measurement model demonstrated no signs of multicollinearity, as indicated by a mean variance inflation factor (VIF) of 2.21 and a maximum VIF value of 2.633, both well below the cutoff value of 5 established by Neter et al. (1985).

4.2 Measurement model analysis

Using SmartPLS-4, the measurement model analysis was conducted to assess the factor loadings that were above the acceptable value of 0.70 (Hair et al., 2016), except three items from RAI (i.e., Just-1, Just-4, N-Mal-1) and one item from BIE (BIE-5). As shown in Table 1, all the remaining element loading values are above the minimum threshold value and range from 0.703 to 0.872, which complements and validates our proposed model.

Table 1 Measurement model: reliability and convergent validity

<i>Construct</i>	<i>Items</i>	<i>Loadings</i>	<i>AVE</i>	<i>Cronbach's α</i>	<i>Rho_A</i>	<i>CR</i>	<i>VIF</i>
RAI	17	0.703–0.772	0.531	0.848	0.849	0.853	2.37
HIU	4	0.798–0.872	0.673	0.838	0.84	0.892	1.929
BIE	4	0.736–0.870	0.662	0.828	0.831	0.886	1.932
LRAIS	6	0.770–0.840	0.642	0.889	0.895	0.915	2.186

Note: RAI – responsible artificial intelligence, BIE – breakthrough innovation engagement, HIU – hybrid intelligence use, AVE – average variance extracted, LRAIS – leaders' RAI symbolisation, CR – composite reliability, VIF – variance inflation factor.

The results further affirm the model's reliability, including the goodness of fit (GOF) at 0.64, exceeding Akter et al. (2011) threshold of 0.36. Additionally, key metrics such as the avg. path coefficient (APC) at 0.35 ($p < 0.05$), avg. VIF at 2.21, and avg. R^2 at 0.67 ($p < 0.05$) collectively attests to the robustness and goodness of the global fit of the research framework. Table 3 demonstrates the goodness of fit statistics, predictive indices, and R^2 values of the complete measurement model

4.3 CFA model fit indices

To meet the research objective of this study, the measurement model was evaluated for discriminant validity, construct reliability, and convergent validity in line with the guidelines provided in (Zulfiqar et al., 2023). The metrics were computed to assess the adequacy of the measurement model. After removing the lower ones, all factor loadings exceeded the threshold needed to proceed with the structural equation modelling (SEM) technique. In addition, reliability assessments were conducted, and the values of composite reliability (CR) and Cronbach's alpha in terms of internal consistency reliability were larger than 0.6 and 0.7, respectively. This confirms the representation of proposed constructs and suggests strong reliability (Hair et al., 2017). Convergent validity (CV) of the instruments was evaluated using the average variance extracted (AVE). Results revealed that each index value had satisfactory convergent validity, as each value exceeded the critical threshold for significance of 0.5 (Hair et al., 2017). Within the current model, the study variables' construct reliability and convergent validity were verified by the results presented in Table 1.

Furthermore, discriminant validity determines the level of difference that is needed to determine the variance in the factors, which is obtained from the square root of the AVE. Accordingly, discriminant validity was established using the Fornell-Larcker criteria (FLC) (Fornell and Larcker, 1981) and the heterotrait-monotrait ratio (HTMT). FLC entails comparing the AVE of each construct with its square of the inter-concept

coefficient relative to other variables in the model. According to the criterion, the AVE score of the former construct should not be higher than the covariance between the two constructs (Hair et al., 2016). Additionally, this study employed HTMT ratios < 1 to distinguish between two components, following the guidance of (Hair et al., 2017). It can be seen from Table 2 that the FLC and HTMT scores indicate the explicit independence and distinctiveness of each construct.

Table 2 Discriminant validity

	<i>BIE</i>	<i>HIU</i>	<i>LRAIS</i>	<i>RAI</i>
<i>HTMT ratio method</i>				
BIE				
HIU	0.801			
LRAIS	0.667	0.627		
RAI	0.817	0.74	0.615	
<i>Fornell-Larcker method</i>				
BIE	0.814			
HIU	0.752	0.821		
LRAIS	0.58	0.547	0.801	
RAI	0.724	0.659	0.568	0.734

Notes: The diagonals value show AVE, and bottom cells represent the variables squared correlations. The HTMT < 1.

Table 3 Model fit indices

<i>Goodness of fit statistics, predictive indices and R²</i>		
	<i>Obtained value</i>	<i>p value/recommended value</i>
Average path coefficient (APC)	0.35	<0.05
Average R-square (AR ²)	0.67	<0.05
Average variance inflation factor (AVIF)	2.21	<5
Goodness of fit (GOF)	0.64	>0.36
	<i>BIE</i>	<i>HIU</i>
R-square (R ²)	0.71	0.62

4.4 Hypothesis testing

Following the assessment of the validity of the proposed model, all hypotheses were tested employing Hayes’ SPSS PROCESS MACRO model 8 through bootstrapping with 5,000 sub-samples at 95 % confidence interval (CI). The hypothesis tests presented in Table 4 showed that RAI has a significant and positive effect on BIE ($\beta = 0.66, t = 12.06, p < 0.001$) and HIU ($\beta = 0.73, t = 18.65, p < 0.001$). There was also a significant positive relationship between the HIU and BIE relationship ($\beta = 0.27, t = 6.12, p < 0.001$). As presented in Table 4, the results confirm our Hypotheses H1, H2, and H3 and indicate that there is a positive correlation between the variables considered in this study.

Table 4 Direct effects

Hypothesis	Relationship effect	Beta	SE	t statistics	p-values	Bootstraps @95%		Conclusion
						LL	UL	
<i>Direct-effect</i>								
H1	RAI → BIE	0.66	0.06	12.06	0.000	0.55	0.77	Significant
H2	RAI → HIU	0.73	0.04	18.65	0.000	0.64	0.81	Significant
H3	HIU → BIE	0.27	0.05	6.12	0.000	0.18	0.37	Significant

Note: * $p < .05$, ** $p < .01$, *** $p < .001$.

4.5 Results of HIU mediation

To examine the indirect influence of RAI on BIE in the presence of HIU, we conducted further analysis using the two-step method. In the initial step, we assessed the significance of the relationship between the independent variable (RAI) and the mediating variable (HIU). Subsequently, we examined the significance of the relationship between the mediating variable (HIU) and the dependent variable (BIE). This process was confirmed in Hypotheses H2 and H3, prompting a further exploration of the mediating role of HIU within the relationship between RAI and BIE. The findings from Table 5 and Figure 2 validate the significance of RAI and BIE mediated by HIU ($\beta = 0.25$, $SE = 0.06$, $p < 0.001$, 95% CL, LL 0.15; UL 0.37). Consequently, Hypothesis 4 is also supported.

Table 5 Direct, indirect and total effects

Constructs	Hybrid intelligence use (HIU)		
	Beta	SE	R ²
<i>Direct-effect</i>			
Responsible AI	0.73***	0.04	0.62***
Breakthrough innovation engagement	0.27***	0.05	0.71***
<i>Indirect effect via HIU</i>			<i>[Bootstraps @95% CI]</i>
(RAI → HIU → BIE)	0.25***	0.06	[0.15, 0.37]

Note: The 95% confidence intervals (CIs) calculated using 5,000 bootstrap samples, with lower and upper limits in brackets.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

4.6 Results of LRAIS moderation analysis

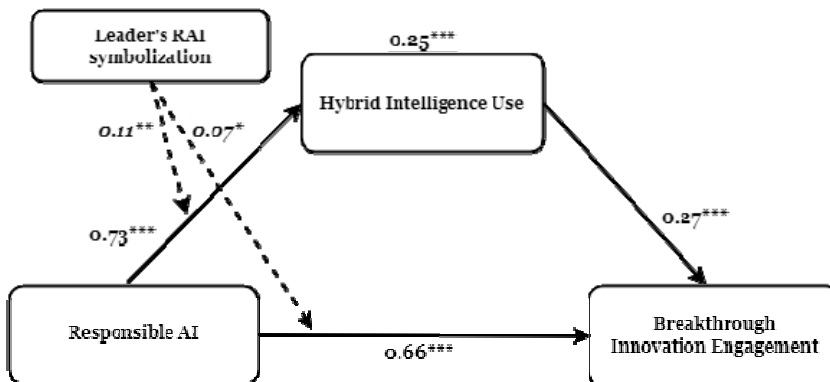
This research employed model 8 and Hayes’ SPSS PROCESS MACRO to explore the moderating role of LRAIS in the relationship between RAI, HIU, and BIE. Specifically, we examined hypotheses H5a and H5b using 5,000 bootstrapping analysis. The findings reveal that LRAIS moderates the direct association between RAI and HIU ($\beta = 0.11$, $SE = 0.04$, $t = 2.76$, 95% CL, LL 0.03; UL 0.18). Additionally, it also moderates the connection between RAI and BIE ($\beta = 0.07$, $SE = 0.03$, $t = 2.25$, 95% CL, LL 0.01; UL 0.13). Hence, Hypotheses H5a and H5b were supported. Moreover, the mediated

moderation exhibited statistical significance (index = 0.03, SE = 0.01, 95% CI, LL 0.01; UL 0.06) (refer to Figure 2 and Table 6 for detailed results).

Table 6 Moderated mediation effects

Constructs	Hybrid intelligence use (HIU)				
	B	SE	t	(95%) CI LL	(95%) CI UL
RAI	0.73	0.04	18.65	0.64	0.81
HIU	-	-	-	-	-
LRAIS	0.008	0.026	0.29	-0.04	0.05
Int_1 (RAI*LRAIS)	0.11	0.04	2.76	0.03	0.18
Int_2 (RAI*LRAIS)	-	-	-	-	-
Constructs	Breakthrough innovation engagement (BIE)				
	B	SE	t	(95%) CI LL	(95%) CI UL
RAI	0.66	0.06	12.06	0.55	0.77
HIU	0.27	0.05	6.12	0.18	0.37
LRAIS	0.02	0.02	1.01	-0.02	0.06
Int_1 (RAI*LRAIS)	-	-	-	-	-
Int_2 (RAI*LRAIS)	0.07	0.03	2.25	0.01	0.13
Moderated mediation analysis					
	Coefficient	SE	(Bootstraps @ 95% CI)		
			LL	UL	
<i>Indirect conditional impact of RAI on BIE through HIU</i>					
LRAIS (-1 SD)	0.22	0.05	0.13	0.33	
LRAIS (+1 SD)	0.29	0.06	0.16	0.41	
<i>Moderated mediation index</i>					
	Index	SE	(Bootstraps @ 95% CI)		
			LL	UL	
	0.03	0.01	0.01	0.06	

Figure 2 Process macro analysis



5 Discussion

The current research investigated mediating and moderating relationships between RAI, HIU, and BIE with a sample of high-tech companies in Pakistan. In addition, it also investigates the role of LRAIS as a moderator in AI-driven hybrid settings. The integrated model provides a high degree of predictive power for BIE. Findings revealed that RAI significantly impacted BIE. These results also sustained extant research, as the transformation of high-tech firms by AI advancements (Lin et al., 2020; Tariq et al., 2024b) affects work design and employee appreciation (Verma et al., 2020), leading to innovative work behaviour (Verma et al., 2020). Also, studies that noted employee's favourable rational attitudes toward AI were influenced by their belief that AI will support their work (Tariq et al., 2024b; Zhu et al., 2021). The results also revealed that RAI positively impacted HIU. This was supported by prior studies, illuminating contributions of AI understanding, trust, and role clarity towards a symbiotic partnership that leads to collective intelligence (AI-HI) and facilitates employees and organisations to create valued outcomes (Chowdhury et al., 2022; Tariq et al., 2024b).

The results further revealed that HIU positively and significantly influences BIE. This result is backed by extant research, as being a significant contributor to exceptional performance, employees using hybrid intelligence are highly motivated and committed to radically creative enterprises, thereby enhancing their degree of engagement in breakthrough innovation (Abbas et al., 2022; Tariq et al., 2024b). Moreover, findings show a positive mediation of HIU between the relationships of RAI and BIE. This result aligns with the interpretations of Caputo et al. (2019), suggesting a carefully crafted strategy helps effective collaboration between human intelligence and AI, which unlocks the potential for significant innovative outcomes. These study findings illude the extension of prior work (Abbas et al., 2022; van de Wetering, 2022), empirically inspecting psychological links illustrating employees innovation engagement.

Findings also revealed that LRAIS moderates the relationship between RAI and HIU. Extending the work of (Abbas et al., 2022; Tariq et al., 2024a; van de Wetering, 2022) elucidates the role of internal resources and leaders' impact on employees' psychological state to engage in creative processes within an AI-driven environment (Azim et al., 2019; Mahmood et al., 2019; Matsunaga, 2022), this study presented LRAIS positively moderates the relationship between RAI and HIU. Findings imply that a shift in employee's perspective through LRAIS motivation enables embracing uncertainty and difficulty arising from AI systems as a source of hope and personal growth (Hannah et al., 2016; Mahmood et al., 2019; Tariq et al., 2024a), ultimately fostering collective intelligence. Similarly, the significant moderation of LRAIS on the relationship between RAI and BIE also matches the findings of prior studies which underscored its role in shaping employee job crafting behaviours.

6 Theoretical implications

This study contributes to several theoretical advances in RAI, hybrid intelligence, and leadership literature. Initially, academic research on the predictive power of RAI in achieving BIE was contributed to through a comprehensive examination. Secondly, this study, while utilising ST and SET, addresses a paucity of research on the influence of AI's ethical incorporation in theory and practice (van de Wetering, 2022). This study

advances the prior knowledge in AI literature by exploring the impact of RAI on employee engagement in innovative projects, thus illuminating psychological pathways driving employee engagement in encounters with cutting-edge technologies (Abbas et al., 2022; Tariq et al., 2024b). Thirdly, the present research adds ST and SET by elucidating RAI as a novel technology that provides cues to employees of its ethical essence and influences social exchanges between AI-employee relationships within the context of high-tech innovation. Moreover, by examining the direct and mediated phenomena between RAI and BIE, this study broadens SET's traditional focus from tangible or emotional benefits to the growing importance of technological resources and benefits in contemporary AI-induced social exchanges.

Likewise, the present study, through the mediation role of hybrid intelligence, contributes to the social exchange framework by explicating that employees' innovation engagement is not solely dependent upon an individual's beliefs and rewards but also significantly influenced by the integration of hybrid intelligence systems. Lastly, this study addresses research scarcity on an organisation's internal resources facilitating AI embracement (Chowdhury et al., 2023; Tariq et al., 2024a, 2024b). Hence, drawing upon the ST, this research advocates the role of LRAIS in leveraging the impact of RAI to capitalise on the hybrid intelligence approach and BIE. Based on the findings, this study adds to ST by highlighting that LRAIS transcends the effectiveness of leaders from a comprehensive resource in traditional settings to transforming followers' perceptions and behaviours in RAI contexts.

7 Practical implications

This study bears several noteworthy managerial implications, particularly within the context of technology-driven enterprises. Results highlight that RAI influences HIU, ultimately impacting BIE. Thus, organisations should implement ethically driven RAI systems in such a way that influences employee's belief of AI support in their work, fostering effective collaboration between human intelligence and AI (Caputo et al., 2019). Moreover, for RAI, organisations should emphasise the bio-ethical aspects of autonomy, beneficence, and non-maleficence while implementing AI systems; more crucially, they should draw employees' attention to AI's explainability and justice to enhance their HIU. Such effective augmentation with the assistive role of hybrid intelligence encourages employees to extend their analytical and intuitive thinking abilities (Raisamo et al., 2019), ultimately enhancing the contribution of one's self to the development of business strategies and organisational performance (Braganza et al., 2021), through engagement in breakthrough innovation.

Moreover, on a technical level, this study stresses that AI developers should ensure transparent RAI design for management and employees, which promotes effective RAI integration and employee BIE. To this end, RAI systems should be designed with clear explanations of their capabilities and limitations. In addition, since present study underscores the essence of AI-employee social exchange in a Pakistani context, ranking high on the collectivism score (Hofstede, 1984). Hence, it is necessary to note that outcomes might be allied to the country's culture towards group harmony and a long-term orientation, emphasising trust and social stability. Furthermore, this study concludes that innovation and HR managers should empower high-tech RAI users by

enriching their understanding of RAI with strong RAI symbolisation among their leaders. This requires organisations adopting RAI to prioritise leadership development programs focused on imparting knowledge and skills related to ethical considerations and establishing trust with employees regarding RAI practices.

8 Limitations and future directions

This study contributes to the existing body of knowledge, yet its limitations indicate avenues for further research. Initially, the focus was on the high-tech industry of Pakistan. While RAI and hybrid intelligence research are often context-specific, conducting replications in diverse settings would enhance the robustness of the research model. Moreover, the findings predominantly reflect an Asian perspective from a developing nation. Future endeavours could offer broader insights by including samples from other developing or developed countries in European or Western economies. To explore the proposed research framework more comprehensively, this study adopted a cross-sectional research design. Subsequent researchers might consider employing longitudinal, mixed-methods, or multi-level research designs. Additionally, delving into in-depth interviews, focus groups, and case studies could provide deeper insights into the study framework.

Moreover, this study confines its examination of signalling and social exchange within the AI-employee relationship to ethical AI integration and leadership dynamics. Future research endeavours could enrich the knowledge base by exploring additional organisational factors, such as organisational support and innovation climate (Verma and Singh, 2022), alongside different leadership styles. It's essential to recognise that concerns like fear, uncertainty, and job displacement are frequently highlighted when dealing with cutting-edge technologies like AI. Additionally, the concept of perceived substitution crisis (PSC) has been extensively discussed in the existing AI literature (Verma and Singh, 2022). Therefore, proposing further investigation into the impact of these variables within the current research paradigm can contribute to addressing the dearth of prior practice-based evidence concerning effective strategies in similar contexts, given the unique nature of the subject matter.

9 Conclusions

The goal of the present work was to analyse the effect of RAI on BIE using data from high-tech firms' employees. The extant literature has revealed that HRM has been redefined, including from an employees' breakthrough innovations standpoint, through AI proliferation. This study tested a structural model with RAI as the independent variable and HIU as mediating with LRAIS as a moderator to capture the employees' BIE in emerging countries. The study results showed that RAI predicted BIE directly and via HIU mediation. Moreover, LRAIS moderation was statistically significant in the relationships between RAI, HIU, and BIE. Furthermore, LRAIS also signalled a crucial moderated-mediation influence on RAI and BIE through HIU's indirect link. Based on the findings of the present study, we believe we have unveiled and provided a thorough discussion for practitioners and academicians for future research.

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