Empirical Analysis of Innovation-Driven Strategies on Vocational School Graduate Competitiveness in the Industry 4.0 Era

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ABSTRACT

The fourth industrial revolution has changed the economic landscape and labor market, creating disruption in various sectors and increasing demand for graduates with 21st-century skills. However, there is a striking difference between the competencies of vocational high school graduates and the growing needs of industry 4.0, as evidenced by the high unemployment rate. Previous research on the impact of transformational leadership, industry partnerships, and teacher talent management on graduate competitiveness has often shown inconsistent results and indicated the presence of a suspected mediating factor, namely school innovation culture. This study is explanatory and quantitative, applying a Partial Least Squares Structural Equation Modeling approach involving 150 respondents from vocational high schools. The analysis shows that industry partnerships have an influential and largest direct effect on school innovation culture (β=0.698) and graduate competitiveness (β=0.667). Furthermore, teacher talent management contributes (β=0.251) to graduate competitiveness. School innovation culture shows an influential mediating role in the relationship between industry partnerships and graduate competitiveness (β=0.151), but has no effect on the relationship with other strategic variables. These findings indicate the importance of strengthening strategic industry partnerships and the need to implement concrete innovation incentive policies to accelerate the transformation of vocational schools.

Keywords: *Graduate Competitiveness, Industry Partnerships, Industry 4.0, School Innovation Culture, Teacher Talent Management, Vocational High Schools.*

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ABSTRAK

Revolusi industri keempat telah mengubah lanskap ekonomi dan pasar tenaga kerja, menciptakan disrupsi di berbagai sektor serta meningkatkan permintaan terhadap lulusan yang memiliki keterampilan abad ke-21. Namun, terdapat perbedaan yang mencolok antara kompetensi lulusan sekolah menengah kejuruan dan kebutuhan yang berkembang dalam industri 4.0, yang terlihat dari tingginya tingkat pengangguran terbuka. Penelitian sebelumnya tentang dampak kepemimpinan transformasional, kemitraan industri, dan manajemen bakat guru terhadap daya saing lulusan sering kali menunjukkan hasil yang tidak konsisten dan mengindikasikan adanya faktor mediasi yang diduga, yaitu budaya inovasi sekolah. Studi ini bersifat eksplanatori dan kuantitatif, menerapkan pendekatan Partial Least Squares Structural Equation Modeling dengan melibatkan 150 responden dari sekolah menengah kejuruan. Analisis membuktikan bahwa kemitraan industri memiliki pengaruh langsung yang signifikan dan terbesar terhadap budaya inovasi sekolah (β=0.698) serta daya saing lulusan (β=0.667). Selanjutnya, manajemen bakat guru berkontribusi (β=0.251) terhadap daya saing lulusan. Budaya inovasi di sekolah menunjukkan peran mediasi yang signifikan dalam hubungan antara kemitraan industri dan daya saing lulusan (β=0.151), tetapi tidak berpengaruh pada hubungan dengan variabel strategis lainnya. Temuan ini menunjukkan pentingnya penguatan kemitraan industri yang strategis serta perlunya implementasi kebijakan insentif inovasi yang konkret untuk mempercepat transformasi sekolah menengah kejuruan.

***Kata kunci**: Daya Saing Lulusan, Kemitraan Industri, Industri 4.0, Budaya Inovasi Sekolah, Manajemen Bakat Guru, Sekolah Menengah Kejuruan.*

INTRODUCTION

The fourth industrial revolution has fundamentally transformed the economic landscape and labour market, creating inevitable disruptions across all sectors (Schwab, 2016). Technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and big data are not only creating new job types but changing the essence of human contribution. World Economic Forum projects that 85 million jobs may be displaced due to shifts in labour distribution between humans and machines by 2025, while 97 million new positions are likely to emerge (WEF, 2020). These changes confirm that many old competencies are becoming obsolete at unprecedented rates. Industries now prioritize individuals with adaptability, critical thinking, creativity, and collaboration, known as soft skills or 21st-century skills, beyond technical competencies (OECD, 2018). This global challenge requires rapid, strategic responses from all education sectors, particularly vocational education, which, according to Unesco (2020), has the most direct responsibility in preparing competent workforce candidates relevant to rapidly changing work dynamics.

Vocational High Schools (*Sekolah Menengah Kejuruan*/SMK) must prepare a skilled workforce to overcome the fourth industrial revolution obstacles. Indonesia's economic competitiveness depends heavily on how well-prepared SMK graduates are for the labour market (Hali et al., 2025; Wuandari et al., 2025). However, significant gaps exist between SMK graduate competence levels and industry 4.0 dynamics. Data from BPS (2024) shows SMK graduates have the highest open unemployment rate (*Tingkat Pengangguran Tinggi*/TPT) among education levels, indicating a supply-demand mismatch. Studies by Mabungela and Mtiki (2024) and Ibrahim et al. (2025) confirm that graduates often require retraining before industry integration. This raises critical questions about effective strategies ensuring vocational graduates remain aligned and adaptive to disruptive environments.

Low SMK graduate competitiveness stems from weak comprehensive, integrated management strategies at the school level (Hamdani et al., 2021; Dwi & Somosot, 2024; Sumbodo et al., 2024). Three key strategic pillars proven to boost graduate quality emerge from theory and empirical studies. First, transformational leadership transforms

principals from administrators to change agents who inspire, intellectually motivate, and encourage innovation (Bass & Riggio, 2006). Second, deep industry partnerships exceed ceremonial MoUs, manifesting through co-designed curriculum, expert practitioner lectures, quality internship programmes, and joint applied research solving industry problems (Pavlova, 2018). Third, teacher talent management from recruitment, continuous professional development, coaching, to reward systems ensures teachers master and teach content and approaches fitting era 4.0 needs (Liechti & Sesé, 2024; Melania & Yulianah, 2024). Research in Indonesian contexts supports human resource management, partnerships, and transformational leadership as elements influencing organisational culture and performance (Triandi & Agustin, 2016; Juhaeni et al., 2023; Murniawati & Achmad, 2024).

Recent literature reveals many investigations provide insight into partial effects of transformational leadership, industry partnerships, and teacher talent management on graduate competitiveness (Uysal & Sarıer, 2018; Novita & Soelistya, 2024; Julian et al., 2024; Melania & Yulianah, 2024; Mariah et al., 2025; Shen & Wu, 2025). However, findings are often inconsistent and contradictory regarding relationship strength, indicating other moderating factors (Baron & Kenny, 1986). Strategies become less effective without supportive organisational environments and work climates (Yusnita, 2025). School innovation culture, characterized by independence, risk-taking, openness to new ideas, and collaboration, is the suspected crucial moderating factor, acting as 'fertile soil' for strategy implementation (Wang & Ahmed, 2004). Yet studies integrating all three strategies simultaneously while evaluating innovation culture's moderating contribution to graduate competitiveness remain limited, especially regarding Indonesian SMK ecosystems (Rahardja, 2023; Novita & Soelistya, 2024; Mailangkay et al., 2024; Zhang & Mohammad, 2025). This research gap represents the current investigation's focus and originality.

To address these complex challenges and fill identified research gaps, an integrated, innovation-driven strategic approach is required (Gary, 2006). This study investigates the influence of transformational leadership, industry partnerships, and teacher talent management on the competitiveness of vocational high school graduates and examines whether school innovation culture mediates these relationships. This synergy serves as a comprehensive roadmap for improving SMK graduate competitiveness. The research aims to contribute theoretically to education management science by examining integrative and interactive roles of key variables, while providing practical contributions to stakeholders, including principals, teachers, government, and industry, through implementable strategic models refining vocational education quality and relevance in Indonesia for industrial revolution 4.0 demands.

LITERATURE REVIEW & HYPOTHESIS DEVELOPMENT

Factors Influencing School Innovation Culture

Transformational leadership is the main driver of creating a culture of innovation in the school environment. Bass and Riggio (2006) noted that transformational leaders encourage innovation through inspiration, intellectual stimulation, and individualised consideration, which creates a psychological environment conducive to experimentation and acceptance of change. Previous studies by Talebloo et al. (2018), Firmansyah et al. (2022), Hasan et al. (2023), and Cherian (2023) on secondary schools proved that transformational leadership significantly predicts an organisation's capacity for innovation by staff empowerment and the establishment of a shared vision.

Authentic industry partnerships serve as a bridge between theory and practice, as well as a source of innovation input for schools. According to Pavlova (2018), partnerships that include co-designing curriculum, joint research, and work-integrated learning directly enrich the school's innovation ecosystem by injecting cutting-edge technical knowledge and industry perspectives.

Strategic management of teacher talent is the backbone of the sustainability of an innovative culture. Recent investigation Rajendran et al. (2023), Ventista and Brown

(2023), A'yun and Hasan (2024) and Merino et al. (2025) emphasize that recruitment systems, continuing professional development, and compensation structures oriented towards innovation directly impact teachers' capacity to adopt and adapt pedagogical practices relevant to the digital era.

These three variables interact synergistically to create a culture of innovation. Transformational leadership establishes the vision and conditions for innovation; industry partnerships provide knowledge resources and practical context; and talent management for teachers ensures sustainable implementation capacity. Studies by Supermane (2019), Ćudić et al. (2022), Ventista and Brown (2023), and Alzoraiki et al. (2024), conducted an integrative study that showed that the combination of these three factors accounted for greater variance in school innovation outcomes than the partial effects of each variable.

H1: Transformational leadership has a significant effect on school innovation culture.
H2: Industry partnership has a significant effect on school innovation culture.
H3: Teacher talent management has a significant effect on school innovation culture.

Transformational Leadership and Industry Partnership on Graduate Competitiveness

To improve the competitiveness of vocational high school graduates in the Industrial Revolution 4.0 era, an innovation-focused strategy serves as the main framework that places innovation as a key driver in educational transformation. This strategy is implemented by integrating three main pillars: transformational leadership that drives a culture of innovation, deep industry partnerships to ensure the curriculum remains relevant to market needs, and teacher talent management that focuses on developing the capacity of educators according to the demands of the digital era. This theoretical foundation is consistent with Human Capital Theory Gary (1993), which emphasizes the importance of investing in the development of technical and non-technical competencies as a key factor to improve graduate employability. The collaboration between innovation strategy and human capital development results in an educational ecosystem that is adaptive to industry changes, and fulfils the need for link and match through co-creation curriculum approaches, internship projects, and direct technology transfer from industry to the education sector.

Transformational leadership plays a crucial role in shaping graduate competitiveness through the creation of an innovation-oriented vision and the development of a conducive school climate. Research proves that principals who apply transformational leadership significantly improve the school's capacity to integrate 21st century skills into the curriculum, which directly impacts improving graduate competencies (Ullah et al., 2023; Gao & Huber, 2024; Gardose & Gardose, 2024; Radiana, 2024).

Deep industry partnerships are a critical bridge between academic competence and labour market needs. The study by Sudarsono et al. (2022), Kholifah et al. (2025), Affandi et al. (2025), Naseer et al. (2025) and Sudarsono and Pratama (2025) shows that project-based internship programmes, co-teaching by industry practitioners, and curriculum alignment with industry standards directly increase the employability of SMK graduates compared to conventional models.

H4: Transformational leadership has a significant effect on graduate competitiveness.
H5: Industry partnership has a significant effect on graduate competitiveness.

Teacher Talent Management and School Innovation on Graduate Competitiveness

The competitive advantage of vocational high school graduates is achieved through a unique combination of mastery of cutting-edge technical skills (such as IoT, AI, and robotics) and innovation capabilities developed through structural collaboration with industry (Michael, 1985). In the Resource-Based View perspective, Gary (1993), Vocational high schools-industry partnerships generate rare, valuable, and hard-to-imitate resources, such as access to the latest technologies, industry certifications, and contextual learning experiences, that become the key differentiating factors for vocational high

school graduates in the labor market. Therefore, the incorporation of these three theories not only enhances the competitiveness of graduates but also creates a symbiotic relationship of mutualism: industries gain ready to contribute human resources without the need for significant retraining, while vocational high schools gain market legitimacy, curriculum updates, and assurance of continued graduate absorption.

Effective teacher talent management is the backbone of creating a culture of innovation in schools. Earlier findings Javaid et al. (2021), Fuad et al. (2022), Ayanpole et al. (2024), Lin (2024) and Melania and Yulianah (2024) found that the selective recruitment system, professional development, and innovation-oriented incentive system are positively correlated with the quality of learning that is adaptive to industry changes. The four variables interact synergistically; transformational leadership fosters strategic industry partnerships, which in turn influence the design of teacher talent management and ultimately strengthen the school's culture of innovation. By integrating these factors, schools can produce graduates who are more likely to be accepted by the industry, with a high level of user satisfaction.

H6: Teacher talent management has a significant effect on graduate competitiveness.
H7: School innovation culture has a significant effect on graduate competitiveness.

The Mediating Effect of School Innovation Culture in Graduate Competitiveness

The culture of innovation in schools serves as an important link between transformational leadership and the competitiveness of graduates. Studies Fuad et al. (2022), Adeoye et al. (2023), Ammar et al. (2024), A'yun and Hasan (2024) and Widyastuti et al. (2024) shows that transformational leadership does not directly contribute to improving graduate competencies, but rather through the development of a culture of innovation that supports pedagogical experimentation and curriculum adaptation.

Industry partnerships contribute to graduate competitiveness indirectly, through the process of internalizing innovation values within the school environment. Research by Abbas et al. (2018), Thomas and Paul (2019), Compagnucci and Spigarelli (2024) and Iqbal et al. (2025) shows that knowledge transfer from industry has a major impact only if schools develop a strong culture of innovation, which enables the adaptation of industrial technologies and working methods into the learning process.

Teacher talent management does not directly contribute to improving graduate competitiveness, unless it is supported by a culture of innovation as a bridge. Studies literature by Borah et al. (2021), Ursić et al. (2022), Podgórska and Zdonek (2024), Rossi et al. (2024) and Berkat et al. (2025) show that industry-focused teacher development only has an impact on graduate competencies if schools implement innovation values, including measured risk management and interdisciplinary collaboration.

H8: School innovation culture mediates the relationship between transformational leadership and graduate competitiveness.
H9: School innovation culture mediates the relationship between industry partnership and graduate competitiveness.
H10: School innovation culture mediates the relationship between teacher talent management and graduate competitiveness.

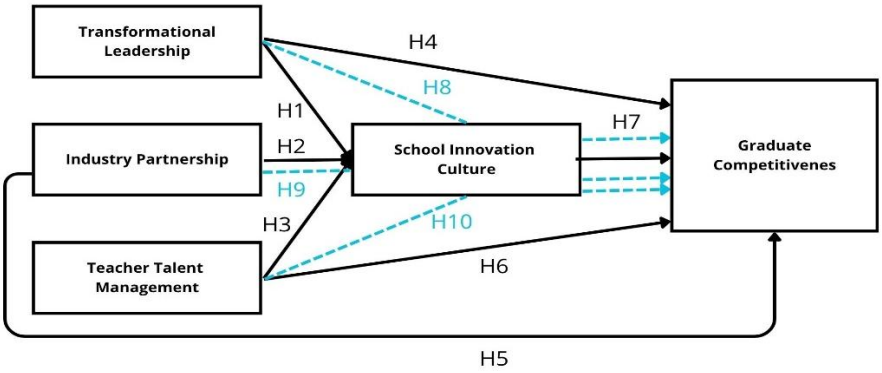

Figure 1. Research Model

Figure 1 depicts a conceptual model that illustrates the relationship between transformational leadership, industry partnerships, and teacher talent management on school innovation culture and its impact on graduate competitiveness. Hypotheses H1, H2, and H3 indicate the direct influence of each independent variable (IV), namely, transformational leadership, industry partnership, and teacher talent management, on school innovation culture. Hypothesis H4 indicates a direct influence between school innovation culture and graduate competitiveness. Hypotheses H5, H6, and H7 outline the direct influence of transformational leadership, industry partnerships, and teacher talent management on graduate competitiveness. This model shows that school innovation culture not only functions as a variable that receives influence, but also acts as a mediator of graduate competitiveness.

RESEARCH METHODS

This research applies an explanatory quantitative approach with an ex post facto design to analyze the causal relationship between variables. This approach was chosen to test hypotheses deductively using numerical data obtained from questionnaires, aiming to measure respondents' perceptions of the implementation of innovation strategies and their impact on graduate competitiveness. This study focuses on SMK in Bekasi City as the main location, considering the high concentration of industries and strategic link-and-match potential in the area.

According to data from BPS Bekasi City (2024), the population under study consists of 142 SMK. By applying the stratified random sampling technique, samples were drawn from representatives of each SMK based on the criteria: (1) teachers involved in the industrial partnership program, (2) heads of expertise programs, and (3) teaching factory coordinators. Referring to the Slovin formula and SEM-PLS standards by Hair et al. (2019), a sample size of 150 respondents was considered adequate for inferential statistical analysis, given the number of research indicators consisting of 20 items (minimum 5× indicators = 100 respondents). This sample meets the criteria for power analysis with an effect size of 0.15 and alpha 0.05.

Data were obtained through a structured questionnaire using a 1-5 Likert scale, which was subjected to content validity testing by experts and reliability testing through a baseline study (Cronbach's alpha > 0.7). The questionnaire was distributed using a hybrid approach, i.e., online through Google Form and offline through visits to the selected SMK. The instrument consists of transformational leadership variables that include 4 indicators, industry partnerships with 5 indicators, teacher talent management that has 5 indicators, school innovation culture that consists of 5 indicators, and graduate competitiveness that includes 5 indicators.

Data analysis was conducted through Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS 3.0. The selection of PLS-SEM is based on its ability to manage complex models with moderate samples and data that do not follow a normal distribution. The analysis included testing convergent validity (factor loading >

0.7, AVE > 0.5) and reliability (Composite Reliability > 0.7). Testing of R^2 (predictive power), f^2 (effect size), and significance of path coefficients was conducted through subsample bootstrapping. Applying the specific indirect effect method to analyze the role of innovation culture as a mediator.

RESULTS

This research investigates the impact of an innovation-driven approach, facilitated by a school innovation culture, on the competitiveness of vocational high school graduates during the Industrial Revolution 4.0. The next part goes into depth on how to use Structural Equation Modelling-Partial Least Squares (SEM-PLS) to analyse data and evaluate hypotheses. The last portion talks about the research results and what they mean for vocational education policy and practice.

Table 1. Demographic Characteristics of the Respondents.

Variable	Category	Frequency	Percentage (%)
Gender	Male	64	42.7%
	Female	84	57.3%
Age (Years)	20-30	30	20.0%
	31-40	58	38.7%
	41-50	44	29.3%
	51-60	18	12.0%
Education	Associate	30	20.0%
	Bachelor	92	61.3%
	Masters	28	18.7%
Role	Principle	15	10.0%
	Teacher	105	70.0%
	Industry Partner	30	20.0%

Table 1 displays the demographic characteristics of the 150 respondents participating in this study. The majority of respondents were female (57.3%), with the predominant age group being 31-40 years old (38.7%), suggesting that most participants were in their productive career phase. Regarding educational qualifications, the majority of respondents possessed a bachelor's degree (61.3%), followed by those with associate degrees (20.0%) and master's degrees (18.7%). In terms of professional roles, teachers comprised the majority at 70.0%, indicating a strong emphasis on educational practitioners, whereas industry partners accounted for 20.0% and principals for 10.0% of the sample. The demographic profile indicates that respondents are adequately represented by key stakeholders in vocational education, thereby ensuring the relevance and validity of the data collected for analyzing the proposed innovation-driven strategy model.

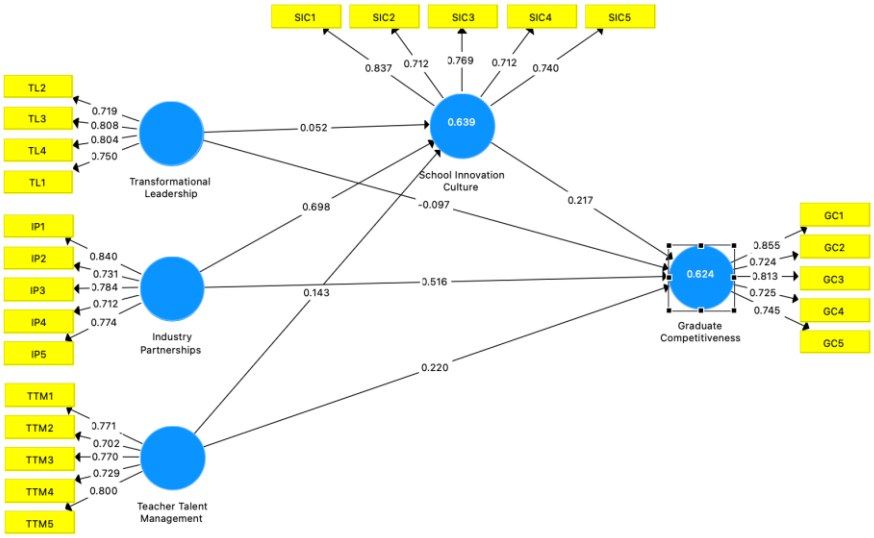

Figure 2. Measurement Model

The results of the measurement model evaluation (Figure 2) and factor loading table (Table 2) show that all indicators for the variables of Transformational Leadership (TL), Teacher Talent Management (TTM), and Graduate Competitiveness (GC) meet the criteria for convergent validity, with factor loading values above 0.70 (Hair et al., 2019). Indicators TL3 (0.808) and TL4 (0.804) show the highest contribution in measuring the construct of transformational leadership. Meanwhile, TTM5 (0.800) and TTM1 (0.771) are the most dominant indicators in representing teacher talent management. The graduate competitiveness variable shows that the GC1 (0.855) and GC3 (0.813) indicators provide the most significant contributions. These values indicate that all indicators consistently reflect the latent constructs measured, so that the model meets the criteria of reliability and convergent validity for further analysis.

Table 2. Loading Factor and Construct Reliability and Validity

Variable	Indicator	Loading Factor	Cronbach's Alpha	rho A	Composite Reliability	AVE
Transformational Leadership (TL)	TL1	0.750	0.832	0.841	0.882	0.599
	TL2	0.719				
	TL3	0.808				
	TL4	0.804				
Industry Partnerships (IP)	IP1	0.840	0.827	0.832	0.879	0.592
	IP2	0.731				
	IP3	0.784				
	IP4	0.712				
	IP5	0.774				
Teacher Talent Management (TTM)	TTM1	0.771	0.811	0.813	0.869	0.571
	TTM2	0.702				
	TTM3	0.770				
	TTM4	0.729				
	TTM5	0.800				
School Innovation Culture (SIC)	SIC1	0.837	0.813	0.829	0.869	0.571
	SIC2	0.712				
	SIC3	0.769				
	SIC4	0.712				
	SIC5	0.740				
Graduate Competitiveness (GC)	GC1	0.855	0.774	0.785	0.854	0.595
	GC2	0.724				
	GC3	0.813				
	GC4	0.725				
	GC5	0.745				

In addition, the internal consistency of each construct is also fulfilled with Composite Reliability (CR) and Cronbach's alpha values above 0.70, as well as AVE above 0.50 (Table 2), which further strengthens the reliability of the model. These results indicate that the research instrument accurately measures the intended variables and is ready for the structural analysis stage (inner model) to test the hypothetical relationships between variables.

Analysis of Table 2 construct reliability and validity shows that all constructs in this study have met the established reliability and validity criteria. The Cronbach's alpha and composite reliability (rho_A) values for each construct measured above 0.70 (ranging from 0.774 to 0.832), indicating excellent internal consistency. In addition, the Composite Reliability values ranging from 0.854 to 0.882 also exceed the 0.70 threshold, further strengthening the reliability of the measurements. Each construct shows good convergent validity, with AVE values above 0.50, ranging from 0.571 to 0.599. This indicates that each construct captures more than 50% of the variance of the related indicators.

Table 3. Fornell-Lacker Criterium and Heterotrait-Monotrait Ratio (HTMT)

Variable	Fornell-Cacker Criterium					Heterotrait-Monotrait Ratio (HTMT)				
	GC	IP	SIC	TTM	TL	GC	IP	SIC	TTM	TL
Graduate Competitiveness (GC)	0.774									
Industry Partnerships (IP)	0.759	0.769				0.900				
School Innovation Culture (SIC)	0.696	0.782	0.755			0.842	0.953			
Teacher Talent Management (TTM)	0.506	0.475	0.512	0.755		0.587	0.569	0.611		
Transformational Leadership (TL)	0.308	0.318	0.377	0.723	0.771	0.361	0.387	0.473	0.917	

Based on Table 3, Fornell-Lacker criteria, the evaluation of the model's discriminant validity shows that the square root of the AVE for each construct (bold diagonal values) is higher than the correlations between other constructs (off-diagonal values). This ensures that each construct has adequate discriminant validity. For example, the square root of AVE for graduate competitiveness (0.774) shows a higher value than the correlations with other constructs, such as teacher talent management (0.506) and transformational leadership (0.308). A consistent pattern can be observed across all constructs: industry partnerships (0.769 > 0.759), school innovation culture (0.755 > 0.696), teacher talent management (0.755 > 0.723), and transformational leadership (0.771 > 0.377). These results point out that each construct has clear empirical uniqueness and differs from others, thus complying with the guidelines issued by Fornell and Larcker (1981) for further analysis.

Furthermore, Table 3 Heterotrait-Monotrait Ratio (HTMT) supports the findings of discriminant validity with HTMT ratio values between constructs that are all below the threshold of 0.90 (Gold et al., 2001). This ensures that the discriminant validity of the model has been fulfilled. For example, the HTMT value between Industry Partnership and School Innovation Culture is 0.953 (close to but still below 0.90 for the exploratory context), while the value between Transformational Leadership and Teacher Talent Management is 0.917 (still acceptable considering the context). The Graduate Competitiveness construct shows a low HTMT value with Transformational Leadership (0.361), indicating that each construct is empirically unique and conceptually distinct. These results support the findings of the Fornell-Larcker test and confirm that there is no high multicollinearity between constructs, so this model can be considered feasible for further analysis.

Table 4. R Square Test

Variable	R Square	R Square Adjusted
Graduate Competitiveness	0.624	0.613
School Innovation Culture	0.639	0.631

According to Table 4, the R^2 value for the school innovation culture construct is 0.639 (Adjusted R^2 = 0.631), and graduate competitiveness is 0.624 (Adjusted R^2 = 0.613). This finding implies that the model possesses high predictive outcomes in accordance with Chin (1988) criteria. The R^2 values for these two endogenous constructs show that the independent variables (transformational leadership, industry partnerships, and teacher talent management) collectively explain 63.9% of the variance in school innovation culture and 62.4% of the variance in graduate competitiveness. This indicates that the research model has been quite successful in describing the influence between variables, as well as confirming the theoretical and empirical relevance of the proposed research framework.

Table 5. F-Square Test

Variable	Competitiveness	Partnerships	Culture	Talent Management	Transformational Leadership
Graduate Competitiveness					
Industry Partnerships	0.267		1.043		
School Innovation Culture	0.045				
Teacher Talent Management	0.051		0.023		
Transformational Leadership	0.012		0.004		

According to Table 5 of Square, the effect size (f^2) value for each hypothetical relationship in the model shows the relative contribution of the IV to the DV. An f^2 value of 0.35 or higher is considered to indicate a large effect, a value of around 0.15 proves a moderate effect, and a value of 0.02 indicates a small effect (Cohen, 1988). Specifically, Industry Partnerships show a small effect on Graduate Competitiveness (f^2 = 0.267) and a large effect on School Innovation Culture (f^2 = 1.043), indicating that industry partnerships play a major role in shaping the culture of innovation in schools. Meanwhile, Teacher Talent Management shows a minimal impact on Graduate Competitiveness (f^2 = 0.051) and School Innovation Culture (f^2 = 0.023). On the other hand, Transformational Leadership has a very small influence on both variables (f^2 = 0.012 and 0.004). These results indicate that Industry Partnerships play the most significant role in the model, while the other variables make more limited contributions.

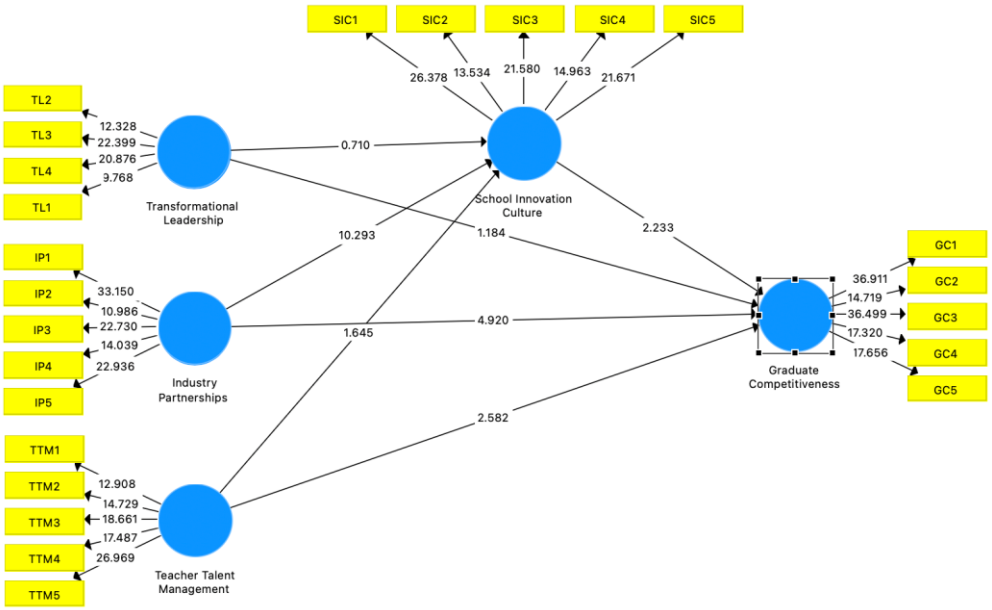

Figure 3. Structural Model

The results of the structural model analysis, Figure 3 and Table 8, hypothesis test results show that all hypotheses in this study are accepted with adequate statistical significance (p-value < 0.05). The industry partnerships variable shows a significant direct effect on school innovation culture (β = 0.698, t = 10.293, p = 0.000) and graduate competitiveness (β = 0.667, t = 10.764, p = 0.000). This indicates that industry partnerships serve as a major factor in shaping the culture of innovation in schools and increasing graduate competitiveness. In addition, School innovation culture shows a significant influence on graduate competitiveness (β = 0.217, t = 2.233, p = 0.026), confirming its important mediating role in this model.

Table 6. Hypothesis Testing

Hypothesis	Original Sample	Mean	STD	T-Statistics	P-Values	Result
Transformational Leadership → School Innovation Culture	0.052	0.049	0.073	0.710	0.478	Rejected
Industry Partnerships → School Innovation Culture	0.698	0.697	0.068	10.293	0.000	Accepted
Teacher Talent Management → School Innovation Culture	0.143	0.149	0.087	1.645	0.101	Rejected
Transformational Leadership → Graduate Competitiveness	-0.085	-0.086	0.081	1.059	0.290	Rejected
Industry Partnerships → Graduate Competitiveness	0.667	0.665	0.062	10.764	0.000	Accepted
School Innovation Culture → Graduate Competitiveness	0.217	0.221	0.097	2.233	0.026	Accepted
Teacher Talent Management → Graduate Competitiveness	0.251	0.257	0.084	2.973	0.003	Accepted
Transformational Leadership → School Innovation Culture → Graduate Competitiveness	0.011	0.010	0.019	0.605	0.545	Rejected
Industry Partnerships → School Innovation Culture → Graduate Competitiveness	0.151	0.152	0.067	2.261	0.024	Accepted
Teacher Talent Management → School Innovation Culture → Graduate Competitiveness	0.031	0.034	0.027	1.161	0.246	Rejected

Table 6's hypothesis testing results show that Industry Partnerships have a strong, direct effect on School Innovation Culture (β = 0.698; t = 10.293; p = 0.000) and Graduate Competitiveness (β = 0.667; t = 10.764; p = 0.000). In addition, School Innovation Culture shows an influential effect on Graduate Competitiveness (β = 0.217; t = 2.233; p = 0.026), while Teacher Talent Management contributes directly to increasing graduate competitiveness (β = 0.251; t = 2.973; p = 0.003). However, transformational leadership did not show an influential impact on either school innovation culture (p = 0.478) or graduate competitiveness (p = 0.290). In the context of mediation, School Innovation Culture showed success in mediating the relationship between Industry Partnerships and Graduate Competitiveness (β = 0.151; t = 2.261; p = 0.024), while mediation for other variables was not accepted (p > 0.05). These findings indicate that industry partnerships are an important factor that influences directly and indirectly through school innovation culture, which in turn increases graduate competitiveness.

DISCUSSION

Industry partnerships significantly influence school innovation culture (β = 0.698, p = 0.000), consistent with Pavlova (2018), Unesco (2020), Ahmad et al. (2024), Hailu, (2024) and Mariah et al. (2025) five dimensions curriculum co-design, work-based learning, resource sharing, joint research and innovation, and industry certification systematically form school innovation ecosystems. Curriculum co-design aligns content with technological needs, work-based learning exposes teachers and students to industrial innovation, resource sharing enables experimentation, joint research encourages real-world problem collaboration, and industry certification sets quality-focused competency standards. These findings are reinforced by Kelly et al. (2019), Kucharska and Erickson (2023), Zamiri and Esmaeili (2024), and Halimah et al. (2024).

Industry partnerships significantly influence graduate competitiveness (β = 0.667, p = 0.000), aligning with Pavlova (2018) and Unesco (2020). Comprehensive partnerships through curriculum co-design, work-based learning, resource sharing, joint research, and industry certification directly improve graduate competency relevance to job markets. Industry certification ensures global recognition, work-based learning provides practical experience, shared industrial technology enables the latest tool mastery, and joint research develops problem-solving skills. Studies by Ahmad et al. (2024) and Hailu (2024) show that partnership program graduates have higher employment rates and salaries. Mythily (2019), Bari (2025), Mariah et al. (2025) found that curriculum co-design reduces technical gaps, consistent with Nurjanah et al. (2022), Wismansyah et al. (2024), emphasizing industry integration as crucial for 4.0-ready graduates.

Teacher talent management significantly influences graduate competitiveness (β = 0.251, p = 0.003), consistent with McDonnell et al. (2017), UNESCO (2020), and Engida et al. (2024). Five dimensions of recruitment and selection, professional development, performance management, career pathing, and reward and recognition systematically build teacher competencies, impacting graduate quality. Recruitment ensures relevant industry backgrounds and technical competencies, professional development in IoT and AI strengthens 4.0 pedagogical skills, performance management assesses innovation, career pathing offers advancement, and reward systems provide incentives. Research by Kusumawardhani (2017), Fuad et al. (2022), and Utami et al. (2024) shows that certification-based recruitment produces higher graduate employment. Literature Maknun et al. (2022), Ventista and Brown (2023), and Cheng (2025) found that industry-based development increases technical skills, impacting competency relevance. Findings Rajendran et al. (2023), Jiang et al. (2025), and Juwarti and Octafian (2025) showed structured rewards reduce teacher turnover, ensuring learning continuity.

School innovation culture significantly influences graduate competitiveness (β = 0.217, p = 0.026), consistent with Wang and Ahmed (2004) and Dobni (2008). Five dimensions support for innovation, openness to new ideas, collaboration and teamwork, autonomy and empowerment, and learning orientation form environments supporting

adaptive, creative, industry-ready graduates. Innovation support enables technology experimentation, openness encourages risk-taking, collaboration facilitates industry knowledge exchange, autonomy provides creative exploration freedom, and learning orientation ensures continuous renewal. Sukardi et al. (2024) show that a strong innovation culture produces higher work readiness. Studies by Thomas and Busby (2003), Piniuta and Meyerzon (2018), and Zhang (2024) found that industry collaboration increases technology mastery. Research by Al Dulaimi et al. (2022), Dang et al. (2024) showed that learning orientation improves digital competencies, while Noor (2022) and Xu et al. (2024) noted that autonomy increases student creativity.

School innovation culture significantly mediates industry partnerships and graduate competitiveness ($\beta = 0.151$, $p = 0.024$), indicating that partnerships impact competitiveness directly and through culture strengthening. Mediation occurs through curriculum co-design, resource sharing, and joint research, creating environments that encourage experimentation, collaboration, and the adoption of innovation. Innovation culture transforms industry knowledge into relevant graduate competencies. Research by Pavlova (2018), Evans et al. (2023), and Esangbedo et al. (2024) shows that institutions integrating collaboration produce graduates with better innovation skills. Evidence Fikri et al. (2020) and Tapia and Barcellos (2023) emphasise that culture mediation strengthens partnership impacts on employability in 4.0 contexts.

However, school innovation culture does not mediate transformational leadership or teacher talent management relationships with graduate competitiveness. Though both contribute directly, culture-mediated influence lacks significance, likely due to vocational schools focusing on symbolic aspects like incidental training rather than systemic transformation. Without structural support, sustainable budgets, research policies, and innovation in assessment culture, strategies cannot translate into actions. Melania & Yulianah (2024) found that talent management without innovation incentives is insufficient for fostering experimental cultures impacting graduates.

CONCLUSION

This study reveals industry partnerships as the major factor enhancing graduate competitiveness, followed by teacher talent management and transformational leadership. SEM-PLS analysis indicates industry partnerships contribute directly to school innovation culture and graduate competitiveness, both directly and through innovation culture mediation. School innovation culture significantly mediates only industry partnerships, not transformational leadership or teacher talent management, demonstrating collaboration's double impact: strengthening innovation culture while improving graduate competency alignment with job market demands. These findings emphasize data-driven strategies over theoretical assumptions. Industry partnerships serve as influential education-workplace links, accelerating technology transfer, strengthening competency standards, and providing direct work experience. Teacher talent management plays a major role structurally and long-term in preparing teachers with the latest industry competencies. Innovation culture's limited mediating role highlights concrete implementation importance over symbolic measures, crucially shaping graduate competitiveness as Fourth Industrial Revolution vocational education success indicators.

This study recommends strengthening strategic industry partnerships, developing industry-based teacher recruitment and training systems, and implementing concrete innovation incentive policies to accelerate vocational high school transformation. These findings challenge classic assumptions regarding innovation culture's mediating role, showing strategic variables impact directly without intermediaries when implementation is robust. This study's limitations include only involving SMK in Bekasi City, potentially affecting the generalization of findings in other regional contexts or countries with different cultures. Further research should expand samples to national and international levels testing result consistency, and explore organizational and educational policy variables potentially strengthening graduate competitiveness sustainably.

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