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The Effects of Technopreneurship and Green Entrepreneurship on Entrepreneurial Skills: The Mediating Role of Digital Literacy among Vocational High School Students in Malang, Indonesia

Ananda Sriphol[1*], Wening Patmi Rahayu[2], Ludi Wishnu Wardana[3], Fadhi Mohammed Awadh Gharamah[4], Syuhadah Che Wae[5]

[1235]Malang State University, Indonesia.
[4]University of Lahej, Yemen.

ananda.sriphol.2404158@students.um.ac.id *✉

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ABSTRACT

Background: High unemployment among vocational high school graduates highlights the need to strengthen entrepreneurial skills. Technopreneurship, green entrepreneurship, and digital literacy offer opportunities to improve students' entrepreneurial competencies in an increasingly digital and sustainability-oriented economy.
Research Gap: Previous studies have examined technopreneurship and green entrepreneurship separately, while their combined relationships with entrepreneurial skills and the mediating role of digital literacy remain insufficiently explored, particularly among Indonesian vocational students.
Novelty: This study integrates technopreneurship and green entrepreneurship into a unified framework, examining digital literacy as a mediator of entrepreneurial skills development within vocational education.
Method: A quantitative explanatory design was employed involving 157 Grade 12 Digital Business students selected through simple random sampling from vocational schools in Malang, Indonesia. Questionnaire data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS 4.
Results: Technopreneurship ($\beta = 0.470$) and green entrepreneurship ($\beta = 0.432$) positively influenced entrepreneurial skills. Digital literacy demonstrated a significant positive relationship with entrepreneurial skills ($\beta = 0.626$). Significant indirect effects were identified for technopreneurship ($\beta = 0.256$) and green entrepreneurship ($\beta = 0.285$), with all reported p-values below 0.001. However, discriminant validity remained problematic (HTMT = 0.976).
Conclusion: Integrating technology-based and environmentally sustainable entrepreneurship education with digital literacy may strengthen vocational students' entrepreneurial competencies. Nevertheless, the measurement model requires further validation before definitive conclusions can be established.

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INTRODUCTION

Entrepreneurial skills development has become a major priority in education, particularly in vocational high schools (SMKs) (Jannah, 2024). As prospective entrepreneurs, vocational students need skills that respond to contemporary economic and technological developments. Entrepreneurial competence enables students to recognize and act on new business opportunities, contributing to economic growth and community well-being (Hahn et al., 2020). Jardim (2021) identifies financial management, innovative business development, integration of technology and economic activities, and the generation of new ideas as essential entrepreneurial competencies.

As a developing country, Indonesia has recognized the importance of entrepreneurial competencies and introduced initiatives such as Making Indonesia 4.0, digital training workshops, financial incentives, and regulatory reforms to encourage digital entrepreneurship (Sudirman & Nurfaisah, 2025). Nevertheless, entrepreneurship programs have not yet formed a sufficiently comprehensive and effective training ecosystem (Yanuarto & Hapsari, 2022). Indonesia has been placed in the lowest quartile among G20 countries for entrepreneurship education in the Global Entrepreneurship and Development Index (Ye & Tan, 2024). Previous reports cited in the literature indicate that entrepreneurship participation in Indonesia remains below that of several neighboring ASEAN countries (Junaidi et al., 2023; Wibowo et al., 2023).

Weak entrepreneurial competencies are also evident among vocational high school graduates. Earlier studies describe employers' concerns about new graduates' work readiness, adaptability, and ability to work under pressure (Owens, 2018; Imjai et al., 2024). Graduates may also lack the creativity and innovative thinking required to establish their own enterprises (Amorós et al., 2021; Douglas & Prentice, 2019). National statistics reported that the unemployment rate among vocational high school graduates reached 9.42%, exceeding the rates recorded for other education levels (Badan Pusat Statistik, 2023).

A similar challenge has been reported in Malang. Regional statistics indicate higher unemployment among vocational high school graduates than among general senior high school graduates (BPS, 2024). Reliance on employment opportunities provided by companies, combined with limited capacity for independent entrepreneurship, may contribute to this pattern (Darman, 2025). Pratiwi et al. (2025) reported relatively low levels of independence among Digital Business students at ten vocational schools in Malang. Although some students could design logos using artificial intelligence and operate online stores, many still lacked practical competencies in opportunity recognition, business-model development, digital marketing, and financial management.

Improving digital literacy is one potential response to these limitations. The Malang Digital Society Index reported scores of 58% for digital literacy and 47% for digital employment (RRI, 2025). Digital literacy encompasses the ability to use and produce digital media, evaluate information, participate in knowledge-sharing networks, and apply computing skills (Mousavi, 2020). These competencies allow students to use digital media and information and communication technologies to recognize business opportunities (Zhao et al., 2023). Previous research associates digital literacy with innovation, digital business development, higher transaction volumes, and more efficient service delivery (Yanto et al., 2022; Mbaeri & Okechukwu, 2023).

However, proficiency with digital tools alone is insufficient in contemporary business. Students also need creativity, innovation, communication, collaboration, and problem-solving skills. Technopreneurship combines technological knowledge and entrepreneurial competencies to create new and adaptable business models (Bomani et al., 2021). The integration of technology and entrepreneurship can empower students to exploit market opportunities and develop competitive advantages (Purwati, 2022; Reddy, 2020). Entrepreneurship education should therefore foster innovative thinking, curiosity, perseverance, and a willingness to confront uncertainty (Onileowo & Muharam, 2024).

Green entrepreneurship is similarly important because it incorporates ecological values into business models. Students need not only to create products but also to develop environmentally responsible products and services (Anabaraonye et al., 2024). Green entrepreneurship can help prepare students for changing economic conditions and encourage independence and innovation (Papageorgiou et al., 2023; Makhloufi et al., 2022). Environmentally oriented enterprises may also contribute to social

change and sustainable business performance (Mia et al., 2022). The development of green products and services increasingly depends on environmentally friendly technologies (Babar & Tahir, 2024).

The Theory of Planned Behavior (TPB) provides the overarching theoretical framework for this study. TPB proposes that attitudes toward behavior, subjective norms, and perceived behavioral control influence behavioral intentions (Mohd Noor & Malek, 2021). In the present context, technopreneurship and green entrepreneurship may shape students' entrepreneurial attitudes and values (Purwati et al., 2023), while digital literacy may strengthen perceived behavioral control in digital business activities (Wang et al., 2023). Entrepreneurial skills are conceptualized as the practical capabilities associated with these educational and technological factors.

Previous studies have investigated technopreneurship and green entrepreneurship as determinants of entrepreneurial competence, often separately. Technopreneurship has been linked to favorable entrepreneurial outcomes (Halim, 2023; Hashimi et al., 2021; Rafiana, 2023), while studies of green entrepreneurship report positive relationships with entrepreneurial skills (Anabaraonye et al., 2024; Mia et al., 2022; Orji et al., 2023). Few studies have examined both constructs simultaneously among vocational students in Malang. Purwati et al. (2023) considered both dimensions but did not find a significant relationship with students' entrepreneurial skills. Moreover, the mediating role of digital literacy remains insufficiently explored. This study therefore investigates the direct and indirect effects of technopreneurship and green entrepreneurship on entrepreneurial skills through digital literacy.

METHOD

This study used a quantitative, descriptive-explanatory research design to investigate relationships among variables. Quantitative methods facilitate theory testing through statistical analysis (Creswell, 2013), while descriptive research characterizes the relevant properties of the variables under investigation (Abdullahi et al., 2021). The population consisted of 263 Grade 12 students enrolled in the Digital Business competency program at vocational high schools in Malang during the 2024/2025 academic year. An online sample-size calculator indicated a required sample of 157 respondents.

Probability sampling, specifically simple random sampling, was used. Primary data were obtained through questionnaires measuring technopreneurship, green entrepreneurship, digital literacy, and entrepreneurial skills. The structural model was analyzed using SmartPLS 4 and partial least squares structural equation modeling (PLS-SEM).

RESULTS

Respondents were recruited from seven vocational high schools in Malang: SMKN 1 Malang, SMK PGRI 2 Malang, SMK PGRI 3 Malang, SMK PGRI 6 Malang, SMK Muhammadiyah 2 Malang, SMK National Media Center, and SMK Ardjuna 2 Malang. SMK PGRI 3 Malang accounted for the largest share of the sample (38%), followed by SMKN 1 Malang (35 students). Most respondents were 17 years old (98%); 120 were female (77%), and 45% reported that their parents' highest educational attainment was senior high school or vocational high school.

Measurement Model

Convergent validity was assessed using outer loadings and average variance extracted (AVE). Outer loadings above 0.70 are generally recommended, although values above 0.50 may be considered in exploratory instrument development (Hair et al., 2021). AVE values above 0.50 indicate that a construct explains more than half of its indicators' variance, and composite reliability values above 0.70 suggest acceptable internal consistency (Hair et al., 2019).

The reported AVE values were 0.784 for technopreneurship, 0.835 for digital literacy, 0.808 for green entrepreneurship, and 0.876 for entrepreneurial skills. Composite reliability values ranged from 0.935 to 0.955, indicating satisfactory convergent validity and internal consistency.

Discriminant validity was evaluated using the Fornell–Larcker criterion and the heterotrait–monotrait ratio (HTMT). Although most HTMT values were below 0.90, the HTMT between digital literacy and entrepreneurial skills was 0.976. This exceeds the commonly used threshold and indicates that discriminant validity has not been established for these two constructs. Favorable Fornell–Larcker results do not resolve this concern. The measurement model should be reassessed, including item

wording, construct overlap, cross-loadings, and bootstrapped HTMT confidence intervals, before definitive interpretation of the structural relationships.

Structural Model

Variance inflation factors (VIFs) were assessed to identify potential collinearity. Reported values ranged from 3.243 to 4.321, below the conventional threshold of 5, although some exceeded the stricter benchmark of 3.3. Thus, severe collinearity is not indicated by the conventional criterion, but potential overlap warrants caution. The reported R^2 values were 0.688 for digital literacy and 0.872 for entrepreneurial skills, indicating that the model explained substantial proportions of variance in these endogenous constructs.

Hypothesis Testing

Bootstrapping was used to evaluate the significance of the hypothesized paths. The hypothesis table reports positive and statistically significant relationships for all seven paths. The estimates in Table 1 are reproduced from the reported hypothesis table and should be checked against the original SmartPLS output before submission.

Hypothesis	Path	β	t	p
H1	Technopreneurship → Digital literacy	0.409	3.387	0.001
H2	Green entrepreneurship → Digital literacy	0.455	3.662	<0.001
H3	Digital literacy → Entrepreneurial skills	0.626	9.107	<0.001
H4	Technopreneurship → Entrepreneurial skills	0.470	4.741	<0.001
H5	Green entrepreneurship → Entrepreneurial skills	0.432	4.236	<0.001
H6	Technopreneurship → Digital literacy → Entrepreneurial skills	0.256	3.152	<0.001
H7	Green entrepreneurship → Digital literacy → Entrepreneurial skills	0.285	3.434	<0.001

DISCUSSION

Technopreneurship and Digital Literacy

Technopreneurship was positively associated with digital literacy ($\beta = 0.409$, $t = 3.387$, $p = 0.001$), supporting H1. Students demonstrated a relatively strong understanding of digital ethics and privacy, including avoiding plagiarism, protecting personal information, and recognizing misinformation. The questionnaire item on understanding ethics and privacy when sharing digital content received a mean score of 3.88. Participation in technology-based entrepreneurial projects may offer opportunities to practice ethical decision-making and strengthen digital competencies. Previous studies similarly emphasize the role of digital literacy in preparing competitive technopreneurs and sustaining digital enterprises (Syukron et al., 2025; Pitaloka & Avianti, 2024; Soomro & Shah, 2021; Nugroho et al., 2025). Within TPB, positive experiences with digital business activities may contribute to favorable attitudes toward technology use and perceived behavioral control (Wijayanto et al., 2023; Anwar & Herayono, 2024).

Green Entrepreneurship and Digital Literacy

Green entrepreneurship had a positive association with digital literacy ($\beta = 0.455$, $t = 3.662$, $p < 0.001$), supporting H2. Integrating environmental sustainability with digital tools can enable students to improve operational efficiency, reach markets, and develop sustainable marketing strategies (Regif et al., 2023). Digital competencies may also facilitate environmentally responsible practices and innovation (Gufron & Al-Majidah, 2025). From a TPB perspective, ecological awareness may support favorable attitudes, while access to digital tools strengthens students' perceived ability to implement sustainable business ideas (Kesa et al., 2024). Vocational schools could build on this relationship through digitally supported green entrepreneurship modules and practical projects.

Digital Literacy and Entrepreneurial Skills

Digital literacy was positively associated with entrepreneurial skills ($\beta = 0.626$, $t = 9.107$, $p < 0.001$), supporting H3. Students with stronger digital competencies may be better equipped to create and edit digital content, use e-commerce platforms, communicate with customers, and manage business information. Such skills can support product development, decision-making, and independent business activity (Adeoye et al., 2024). This finding is consistent with research linking digital literacy to entrepreneurial competence and business performance (Novela et al., 2024). In TPB terms, digital proficiency may increase perceived behavioral control and confidence in translating entrepreneurial intentions into action (Shatila et al., 2026).

Technopreneurship and Entrepreneurial Skills

Technopreneurship was positively associated with entrepreneurial skills ($\beta = 0.470$, $t = 4.741$, $p < 0.001$), supporting H4. Technology-based entrepreneurial learning can provide opportunities to generate business ideas, develop products, plan activities, and implement digital marketing. Practical involvement in entrepreneurial projects has been linked to opportunity recognition, risk-taking, and self-confidence (Imam Agung et al., 2018; Zaki et al., 2021; Widhi et al., 2024). School support, including facilities and experiential learning, may help students strengthen these competencies. The relationship can also be understood through TPB, as positive experiences, peer and teacher support, and perceived capability may encourage entrepreneurial behavior (Dwi Ananda, 2023; Ngoma et al., 2024).

Green Entrepreneurship and Entrepreneurial Skills

Green entrepreneurship was positively associated with entrepreneurial skills ($\beta = 0.432$, $t = 4.236$, $p < 0.001$), supporting H5. The interpretation follows the reported hypothesis table; confirmation against the original SmartPLS output remains necessary. Green entrepreneurship education can provide students with practical experience in designing environmentally responsible products and services, developing green innovations, and applying sustainability principles (Qazi et al., 2020; Al-Mamary, 2025). Under TPB, environmental values, support from teachers and peers, and students' confidence in their capabilities may reinforce responsible entrepreneurial intentions and practices (Liu & Peng, 2025; Yasir et al., 2023).

The Mediating Role of Digital Literacy in the Technopreneurship–Entrepreneurial Skills Relationship

The indirect effect of technopreneurship on entrepreneurial skills through digital literacy was positive and statistically significant ($\beta = 0.256$, $t = 3.152$, $p < 0.001$), supporting H6. Digital literacy may help students convert technology-based entrepreneurial knowledge into practical skills, including identifying opportunities, designing marketing strategies, evaluating business performance, and producing promotional content. Related research emphasizes the importance of technological competence, creativity, and evidence-based decision-making in entrepreneurship (Dewantara & Andi, 2024; Maula et al., 2021; Wulandari et al., 2025). In TPB terms, digital competence may reinforce perceived behavioral control and students' confidence in implementing technology-enabled business ideas (Nugroho et al., 2025).

The Mediating Role of Digital Literacy in the Green Entrepreneurship–Entrepreneurial Skills Relationship

The indirect effect of green entrepreneurship on entrepreneurial skills through digital literacy was also positive and significant ($\beta = 0.285$, $t = 3.434$, $p < 0.001$), supporting H7. Environmental awareness can inspire sustainable business ideas, while digital literacy enables students to research materials, design products, market goods, and evaluate customer responses (Uvarova et al., 2021; Irawan et al., 2026; Wahjoedi et al., 2023). At vocational schools in Malang, recycling projects and environmentally responsible product development may be combined with online design resources and digital marketing. These activities can foster creativity, critical thinking, problem-solving, and business confidence while emphasizing sustainability rather than profit alone.

CONCLUSION

The findings suggest that entrepreneurial skills among Digital Business students at vocational high schools in Malang are associated with technological competencies and an understanding of environmentally sustainable entrepreneurship. Technopreneurship and green entrepreneurship were positively related to digital literacy and entrepreneurial skills, and digital literacy showed significant indirect effects in both relationships. Students who engage with digital business tools and sustainability-oriented activities may be better positioned to recognize opportunities, develop business ideas, and manage enterprises independently. Nevertheless, the discriminant-validity concern identified for digital literacy and entrepreneurial skills limits the strength of the conclusions until the measurement model has been reassessed.

Vocational schools should strengthen experiential entrepreneurship learning that integrates digital technologies with environmental responsibility. Appropriate facilities, practical entrepreneurship programs, and teacher professional development may improve implementation. Future research could investigate other regions and educational levels, include additional explanatory factors, and address the measurement-model limitations identified in this study.

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AUTHOR CONTRIBUTION STATEMENT

Ananda Sriphol, Wening Patmi Rahayu, Ludi Wishnu Wardana, Fadhi Mohammed Awadh Gharamah, and Syuhadah Che Wae contributed to the development of this research on technopreneurship, green entrepreneurship, digital literacy, and entrepreneurial skills among vocational high school students. The research activities encompassed conceptualization, literature review, methodological development, questionnaire-based data collection, statistical analysis using partial least squares structural equation modeling (PLS-SEM), interpretation of findings, and manuscript preparation. The specific responsibilities of each author should be confirmed before publication to ensure accurate attribution in accordance with the Contributor Roles Taxonomy (CRediT). All authors should review and approve the final manuscript and accept responsibility for their respective contributions to the research.

AI DISCLOSURE STATEMENT

The manuscript underwent English-language translation, proofreading, and academic language refinement with the assistance of artificial intelligence (AI)-based tools. These tools were used to improve grammatical accuracy, sentence structure, terminology consistency, and overall readability. AI-assisted editing was not intended to generate or modify the original research data, statistical results, or substantive research findings. The authors retain full responsibility for verifying the accuracy, integrity,

and originality of the manuscript, including all AI-assisted revisions. The use of AI tools does not replace the authors' intellectual contributions or accountability for the published work.

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CONFLICTS OF INTEREST

The authors declare that they have no known financial or personal relationships that could have inappropriately influenced the research reported in this manuscript, subject to confirmation by all contributing authors. The study examines the relationships among technopreneurship, green entrepreneurship, digital literacy, and entrepreneurial skills among vocational high school students in Malang, Indonesia. Any institutional affiliations, financial interests, professional relationships, or other circumstances that could reasonably be perceived as influencing the research process or interpretation of findings must be disclosed before publication. All authors are responsible for ensuring the completeness and accuracy of this declaration.

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