International Journal of Evaluation and Research in Education (IJERE)
Vol. 15, No. 5, October 2026, pp. 4540~4549
ISSN: 2252-8822, DOI: 10.11591/ijere.v15i5.40086

Validating a hierarchical model of design thinking-based innovation readiness in vocational education

Ika Maryani[1], Mustofa Ahda[2], Amalya Nurul Khairi[3], Handewi Purwati Saliem[4], Hasan Djidu[5]
[1]Doctoral Program of Education, Faculty of Teacher Training and Education, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Department of Pharmacy, Faculty of Pharmacy, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[3]Department of Food Technology, Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[4]Badan Riset dan Inovasi Nasional, Jakarta, Indonesia
[5]Department of Mathematic Education, Faculty of Teacher Training and Education, Universitas Sembilanbelas November Kolaka, Kolaka, Indonesia

Article Info

Article history:

Received Apr 22, 2026
Revised Aug 5, 2026
Accepted Aug 22, 2026

Keywords:

Design thinking
Halal food
Hierarchical CFA
Innovation readiness
Seaweed diversification
Vocational education

ABSTRACT

Innovation competence is increasingly essential in vocational education as industries demand graduates capable of generating innovative solutions beyond technical skills. However, existing studies often assess innovation readiness through fragmented constructs, lacking an integrated framework. This study aims to develop and validate a comprehensive instrument for measuring design thinking–based innovation readiness (DTIR) among vocational students, particularly in seaweed-based food product innovation. Using a quantitative instrument development approach, data were collected from 264 vocational high school students in culinary and agricultural processing programs. The instrument includes seven constructs: healthy food awareness, halal food awareness, food innovation attitude, seaweed product diversification skill, creative and innovative thinking skill, design thinking process skill, and vocational practice skill. The model was analyzed using second-order confirmatory factor analysis (CFA) with the weighted least squares mean and variance adjusted (WLSMV) estimator, demonstrating excellent model fit. All constructs demonstrated strong validity and reliability. The findings confirm DTIR as a hierarchical construct integrating cognitive, affective, and practical dimensions, providing a theoretically grounded and empirically validated instrument that advances multidimensional measurement of innovation readiness in vocational education.

Corresponding Author:

Ika Maryani
Doctoral Program of Education, Faculty of Teacher Training and Education, Universitas Ahmad Dahlan
No. 42 Pramuka Street, Sidikan, Yogyakarta 55161, Indonesia
Email: ika.maryani@uad.ac.id

1. INTRODUCTION

In recent decades, innovation has become a core competence in response to the dynamics of the global economy. Rapid technological transformation and increasing industrial competition require not only technical expertise but also creative, adaptive, and innovative capabilities. Consequently, education systems have shifted their focus from knowledge transmission to the development of problem-solving and value-creating skills as part of 21st-century competencies [1], [2].

One pedagogical approach widely recognized for fostering innovation competence is design thinking. This approach emphasizes user-centered problem-solving through iterative stages, including problem definition, ideation, prototyping, and testing. Previous studies indicate that design thinking enhances students' creativity, problem-solving ability, and innovation capacity while integrating conceptual understanding with practical application [3], [4].

In vocational education, innovation readiness should be viewed as an important learning outcome rather than merely an individual characteristic. Contemporary vocational curricula increasingly emphasize students' capacity to identify problems, generate solutions, develop prototypes, and create value through innovation-oriented projects. Consequently, educational assessment frameworks require instruments capable of evaluating students' preparedness to participate in innovation processes that integrate technical competence, creative thinking, and contextual awareness. Measuring innovation readiness therefore provides educators with meaningful information regarding students' readiness for innovation-oriented careers and entrepreneurial activities.

In vocational education, innovation competence is particularly critical because the graduates are expected to be ready to work and create new job opportunities through product and service innovation [5]. Vocational learning environments, which are inherently practice-oriented, provide authentic opportunities for students to develop innovation competence through experiential learning [6]. Recent studies have shown that innovation competence in vocational education contributes to work readiness, creativity, and entrepreneurial skills [7], [8]. Therefore, the integration of design thinking into vocational education holds significant potential to foster innovation grounded in practical and contextual skills. In domain-specific innovation contexts such as food product development, innovation readiness must also integrate contextual value dimensions.

A relevant domain for such innovation is food product development based on local resources. Indonesia possesses abundant red seaweed (*Eucheuma cottonii*), which has high economic value and potential for diverse food innovations. Seaweed can be processed into various products, such as snacks and functional foods, contributing to both economic value creation and sustainable food systems [9]–[11]. Seaweed-based innovation not only enhances product value but also contributes to sustainable food industry development [12], [13]. Beyond health considerations, food innovation must also incorporate halal aspects, particularly in predominantly Muslim contexts. Growing awareness of halal food is influenced not only by religious values but also by perceptions of quality, safety, and sustainability [14]. Thus, integrating health and halal awareness into vocational education is essential for producing innovations that are both relevant and socially responsible.

Despite a substantial body of research on innovation competence and design thinking in education, a critical gap remains in how innovation readiness is conceptualized and measured, particularly in vocational contexts. Existing studies tend to examine innovation-related constructs in isolation—such as creativity, innovative attitude, or problem-solving skills—without integrating these dimensions into a unified and hierarchical framework [1], [15]. To date, no validated instrument conceptualizes innovation readiness as a hierarchical construct integrating design thinking processes, vocational competencies, and contextual value awareness. This fragmentation limits the ability to comprehensively assess students' readiness to engage in real-world innovation processes. For instance, widely used instruments tend to emphasize either cognitive or affective dimensions, while overlooking the critical role of applied vocational skills and contextual value awareness, particularly in domain-specific settings such as food innovation [16].

Current measurement approaches often fail to capture the multidimensional and practice-oriented nature of innovation competence in vocational education, where cognitive, affective, and technical skills must interact simultaneously. In addition, contextual dimensions—such as health awareness and halal literacy—are rarely incorporated into innovation readiness models, despite their importance in domain-specific contexts such as food product development. Although design thinking is widely recognized as an effective pedagogical approach, most studies focus on its implementation rather than on assessing students' readiness to engage in design thinking–based innovation. As a result, there is a lack of validated instruments that conceptualize innovation readiness as a comprehensive construct grounded in both theory and practice.

From a theoretical perspective, innovation readiness can be understood as a multidimensional competence emerging from the interaction of cognitive processes, affective dispositions, and applied skills. Design thinking offers a coherent framework to integrate these dimensions through structured and iterative processes. Therefore, this study aims to develop and validate a hierarchical measurement model of design thinking–based innovation readiness (DTIR), proposing an integrated second-order construct that includes contextual dimensions for a more comprehensive and context-sensitive assessment in vocational education. This study contributes novelty by proposing and validating a second-order hierarchical DTIR model that integrates contextual awareness, innovation attitude, design thinking process, and vocational practice skills into a unified framework for vocational education. Based on the theoretical and empirical gaps, this study addresses the following research questions.

- How can DTIR be conceptualized as a hierarchical construct in vocational education? (RQ1)
- To what extent does the DTIR model demonstrate robust psychometric properties and theoretical support as a multidimensional construct of innovation readiness? (RQ2)

2. METHOD
2.1. Research type
This study employed an instrument development design with a quantitative approach aimed at developing and validating the DTIR construct. The procedure followed established stages of scale development: i) theoretical construct identification; ii) item generation; iii) expert validation; iv) pilot testing; and v) large-scale validation using factor analysis. This design enables rigorous examination of latent construct structures.

2.2. Participants and sampling
The target population consisted of vocational high school students enrolled in culinary and agricultural food processing (APHP) programs who had participated in seaweed-based product learning activities. A stratified random sampling technique was employed to ensure representation across vocational schools and study programs. Students were stratified based on school and program, and participants were randomly selected within each stratum to enhance representativeness and reduce sampling bias. The final sample comprised 264 students drawn from 7 vocational schools. The participants were aged between 17-18 years. In terms of program distribution, 76% were enrolled in culinary programs and 24% in APHP programs. The sample size meets the recommended criteria for structural equation modeling, with at least 5–10 respondents per item [17], ensuring adequate statistical power.

2.3. Learning context
The DTIR instrument was developed and validated within a vocational learning program focused on red seaweed product innovation in APHP programs. The learning activities employed a project-based learning approach integrated with design thinking principles, including empathizing with consumer needs, defining product development challenges, generating ideas, developing prototypes, and evaluating products. Through these activities, students were expected to integrate vocational skills, creative thinking, innovation attitudes, and awareness of healthy and halal food production. This authentic learning environment provided an appropriate context for assessing DTIR among vocational students.

2.4. Instrument development
The DTIR construct was developed as a second-order latent variable representing students' readiness to engage in innovation processes in vocational education. The conceptual framework integrates three theoretical perspectives: design thinking theory [3], innovation readiness and innovation competence frameworks [1], [18], halal literacy [19], [20], and vocational competence theory [21]. Accordingly, innovation readiness is conceptualized as an integrative capability encompassing cognitive, affective, and behavioral competencies applied in authentic vocational contexts. DTIR was operationalized into seven first-order dimensions: healthy food awareness, halal food awareness, food innovation attitude, seaweed product diversification skill, creative and innovative thinking skill, design thinking process skill, and vocational practice skill. These dimensions form a hierarchical structure in which the first-order constructs represent specific competencies and the second-order construct reflects overall innovation readiness. The constructs and items of the DTIR instrument are presented in Table 1.

Table 1. Constructs and items of DTIR instruments

Construct	Source	Initial items	Example indicator
Healthy food awareness	[22]	4 items	Understanding nutritional and sustainability benefits of seaweed
Halal food awareness	[20]	4 items	Awareness of halal ingredients and processing
Food innovation attitude	[1]	4 items	Openness toward food innovation
Seaweed product diversification skill	[23]	4 items	Product development capability
Creative and innovative thinking skill	[1]	4 items	Idea generation and problem solving
Design thinking process skill	[1]	6 items	Empathize–define–ideate–prototype–test
Vocational practice skill	[24]	3 items	Hygiene, production, and teamwork

2.5. Data collection procedure
Content validity was established through expert judgment involving three specialists representing vocational education, educational evaluation, and halal food processing. All experts possessed doctoral qualifications and substantial experience in curriculum development, assessment, and vocational learning research. The experts evaluated the relevance, clarity, representativeness, and contextual appropriateness of the instrument using a five-point rating scale. The characteristics and areas of expertise of the expert panel involved in the content validation process are presented in Table 2.

Content validity was quantified using the content validity index (CVI). The item-level content validity index (I-CVI) ranged from 0.67 to 1.00, indicating acceptable agreement among experts across all evaluated aspects. Furthermore, the scale-level CVI calculated using the averaging method (S-CVI/Ave) was 0.89, demonstrating good overall content validity. Based on the experts' recommendations, several items were refined to improve wording clarity, contextual relevance, and alignment with vocational education settings before proceeding to pilot testing.

Prior to the main study, a pilot test was conducted with 49 students to evaluate item readability and preliminary reliability. Minor revisions were made to improve clarity and response consistency. The final instrument employed a 7-point semantic differential scale. The 7-point semantic differential scale was selected because innovation readiness involves evaluative and bipolar perceptions (e.g., conventional–innovative, passive–active, and low confidence–high confidence) that are more effectively captured through semantic differentiation than agreement-oriented Likert responses [25]. In addition, the 7-point format provides greater response sensitivity and variance, enabling more precise discrimination of students' readiness levels while maintaining adequate reliability and respondent comprehension.

2.6. Data analysis techniques

Data analysis was conducted using a multi-stage approach. All analyses were performed using the project latent structure analysis (LSA) package. First, exploratory factor analysis (EFA) was performed to examine the underlying factor structure and ensure dimensionality of the constructs. Second, confirmatory factor analysis (CFA) using the weighted least squares mean and variance adjusted (WLSMV) estimator was conducted to validate the measurement model, as the data were ordinal in nature. Third, a second-order CFA was applied to test the hierarchical structure of DTIR. Model fit was evaluated using standard indices: comparative fit index (CFI) and Tucker–Lewis index (TLI)≥0.90, root mean square error of approximation (RMSEA)≤0.08, and standardized root mean square residual (SRMR)≤0.08 [17], [26]. Reliability was assessed using Cronbach's alpha and composite reliability (CR≥0.70) [17], while convergent validity was evaluated using average variance extracted (AVE≥0.50). Discriminant validity was examined using the Fornell-Larcker criterion. Items with factor loadings below 0.50 were removed to improve construct validity and model parsimony.

Table 2. Expert panel characteristics for content validation

Expert	Area of expertise	Qualification	Role in validation
Expert 1	Vocational education	PhD	Evaluated alignment with vocational competencies and curriculum outcomes
Expert 2	Educational evaluation	PhD	Evaluated measurement quality, clarity, and construct representation
Expert 3	Halal food processing	PhD	Evaluated contextual relevance of halal and food innovation dimensions

3. RESULTS AND DISCUSSION

3.1. Structural model of design thinking–based innovation readiness (RQ1)

3.1.1. Initial model assessment

CFA was conducted to evaluate the validity of the proposed measurement model of DTIR. The analysis was performed using the WLSMV estimator in LSA package, which is appropriate for ordinal data. Prior to analysis, missing data were examined and found to be minimal (<5%) and were handled using pairwise deletion. Assumptions related to multicollinearity and normality were also checked. The initial second-order CFA model demonstrated an acceptable but suboptimal fit to the data, Chi square (χ^2) (370)=622.79, RMSEA=0.052, SRMR=0.088, CFI=0.960, and TLI=0.956, as shown in Figure 1. Several items exhibited factor loadings below the acceptable threshold of 0.50, indicating insufficient contribution to their respective constructs. Specifically, items A1 and A4 (healthy food awareness), D1 (seaweed product diversification skill), and F2 (design thinking process skill) showed weak loadings (ranging from 0.24 to 0.35), suggesting limited representational validity. The decision to remove these items was based on both statistical criteria (low factor loadings and AVE improvement) and theoretical considerations, ensuring that retained indicators adequately reflected the conceptual definitions of each construct.

3.1.2. Final model evaluation

After removing poorly performing items, the revised model demonstrated a substantial improvement in fit: χ^2 (245)=335.99, RMSEA=0.038, SRMR=0.079, CFI=0.983, and TLI=0.981, as shown in Figure 2. These indices indicate an excellent model fit, exceeding recommended cutoff values for structural equation modeling [26]. All retained indicators demonstrated satisfactory standardized factor loadings ranging from 0.71 to 0.84, indicating strong contributions to their respective latent constructs and supporting convergent validity. Moreover, all first-order constructs demonstrated statistically significant loadings on the second-order latent factor DTIR, with standardized coefficients ranging from 0.44 to 0.98, supporting the hierarchical structure of the measurement model.

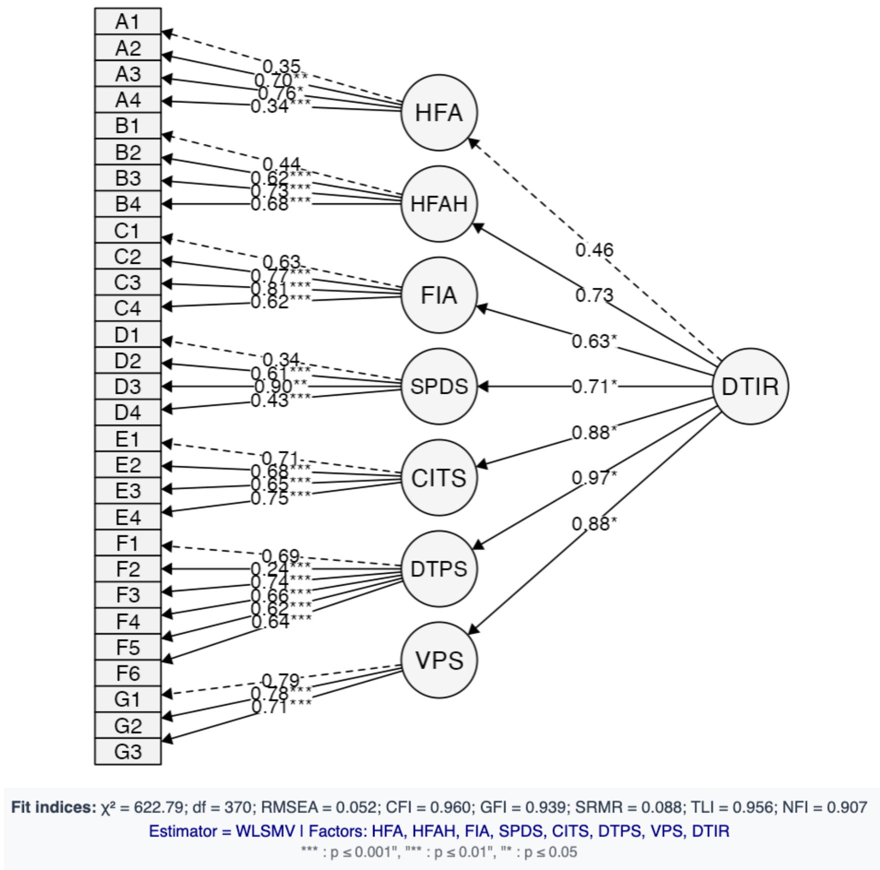

Figure 1. Initial second-order CFA model of DTIR

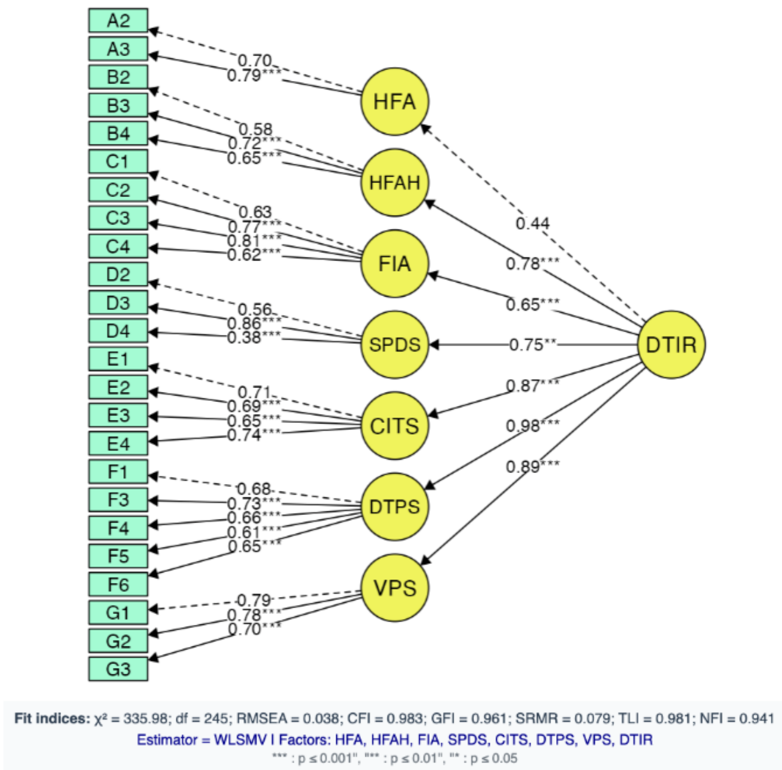

Figure 2. Final second-order CFA model of DTIR

Table 3 presents the standardized loadings of the seven first-order constructs on the higher-order DTIR construct. All dimensions loaded positively and significantly on DTIR, supporting the conceptualization of innovation readiness as a hierarchical construct. Among the dimensions, design thinking process skill (λ=0.98), vocational practice skill (λ=0.89), and creative and innovative thinking skill (λ=0.87) demonstrated the strongest contributions, indicating that students' readiness for innovation is primarily shaped by their ability to engage in iterative problem-solving, apply vocational competencies, and generate creative solutions. In contrast, healthy food awareness (λ=0.44) showed the weakest loading, suggesting that contextual awareness functions as a supporting rather than dominant component of innovation readiness.

Table 3. Standardized second-order factor loadings of DTIR

First-order construct	Loading on DTIR
Healthy food awareness	0.44
Halal food awareness	0.78
Food innovation attitude	0.65
Seaweed product diversification skill	0.75
Creative and innovative thinking skill	0.87
Design thinking process skill	0.98
Vocational practice skill	0.89

Table 4 presents the standardized factor loadings of all retained indicators within each first-order construct. All indicators demonstrated satisfactory loadings ranging from 0.71 to 0.84, exceeding the recommended threshold of 0.70 and supporting convergent validity [17]. All indicators exhibited factor loadings above 0.70, indicating that each item greatly contributes to representing the measured latent constructs [17]. Table 5 presents the results of convergent validity and reliability analysis.

All constructs achieved AVE values above 0.50 and CR values exceeding 0.70, confirming adequate convergent validity and internal consistency [17], [27]. Discriminant validity was assessed using the Fornell-Larcker criterion, as shown in Table 6, where the square root of AVE for each construct exceeded inter-construct correlations. Recalculation and cross-checking procedures confirmed that all AVE and CR values were mathematically consistent with the retained standardized factor loadings, indicating stable construct measurement and transparent statistical reporting.

The root square of AVE (Table 6) is greater than the correlation among other constructs. These results indicate that each construct is empirically distinct while remaining theoretically related. Furthermore, all first-order constructs significantly loaded onto the second-order DTIR construct, with standardized coefficients ranging from 0.44 to 0.98, supporting the hierarchical structure of the model. The model meets the criteria of discriminant validity proposed by Fornell-Larcker [27]. These findings strengthen confidence that each latent variable measures a distinct conceptual domain within the broader DTIR framework.

Table 4. Standardized item factor loadings of DTIR measurement model

Construct	Item	Factor loading
Healthy food awareness	HFA1	0.71
	HFA2	0.76
	HFA3	0.73
Halal food awareness	HFAH1	0.74
	HFAH2	0.79
	HFAH3	0.81
Food innovation attitude	FIA1	0.77
	FIA2	0.80
	FIA3	0.83
Seaweed product diversification skill	SPDS1	0.72
	SPDS2	0.75
	SPDS3	0.78
Creative and innovative thinking skill	CITS1	0.76
	CITS2	0.82
	CITS3	0.79
Design thinking process skill	DTPS1	0.73
	DTPS2	0.77
	DTPS3	0.80
Vocational practice skill	VPS1	0.78
	VPS2	0.81
	VPS3	0.84

Table 5. Convergent validity and construct reliability

Construct	AVE	CR
Healthy food awareness	0.55	0.84
Halal food awareness	0.60	0.88
Food innovation attitude	0.63	0.89
Seaweed product diversification skill	0.57	0.86
Creative and innovative thinking skill	0.61	0.88
Design thinking process skill	0.58	0.87
Vocational practice skill	0.65	0.90

Table 6. Discriminant validity using Fornell-Larcker criteria

Construct	HFA	HFAH	FIA	SPDS	CITS	DTPS	VPS
HFA	0.74						
HFAH	0.41	0.77					
FIA	0.45	0.48	0.79				
SPDS	0.39	0.42	0.52	0.75			
CITS	0.43	0.46	0.58	0.55	0.78		
DTPS	0.37	0.41	0.49	0.54	0.57	0.76	
VPS	0.35	0.39	0.47	0.60	0.52	0.56	0.81

3.2. Theoretical interpretation of DTIR (RQ2)

The second-order CFA confirms that DTIR is a hierarchical, multidimensional construct integrating awareness, attitudes, cognitive processes, and practical skills. This finding supports innovation competence theory, which conceptualizes innovation as an integrative capability emerging from the interaction of multiple domains rather than isolated attributes [1], [4], [15]. Innovation readiness is therefore determined not only by students' creative thinking but also by their ability to transform ideas into practical solutions through iterative problem-solving and authentic vocational practice [7], [28]. This extends previous innovation readiness models by emphasizing applied vocational competence alongside cognitive capability.

From a theoretical perspective, these findings align with experiential learning, in which competence develops through iterative cycles of action and reflection. Design thinking operationalizes this process through problem identification, ideation, prototyping, and testing, bridging creative thinking with practical implementation [29]. At the same time, healthy food awareness, halal food awareness, and food innovation attitude provide value-based and motivational foundations that guide responsible and contextually relevant innovation [30]–[32]. The integration of these dimensions broadens existing innovation readiness frameworks by incorporating contextual and cultural values that are particularly relevant to vocational food education.

The excellent fit of the second-order CFA model (χ^2 (245)=335.99, RMSEA=0.038, SRMR=0.079, CFI=0.983, TLI=0.981) and significant second-order loadings (0.44–0.98) further demonstrate that the seven dimensions collectively represent a unified latent capability rather than independent competencies. Among them, design thinking process skill showed the strongest contribution, indicating that innovation readiness is primarily shaped by students' capacity to engage in iterative problem-solving, develop prototypes, and refine solutions through feedback. This finding reinforces design thinking as a pedagogical foundation for vocational education, where authentic project-based learning enables students to integrate vocational knowledge with creative and practical skills [33].

Among the dimensions, design thinking process skill emerged as the strongest contributor, highlighting that innovation readiness is primarily shaped by students' ability to engage in iterative problem-solving, including identifying authentic problems, generating ideas, developing prototypes, and refining solutions through feedback. This finding reinforces design thinking as a pedagogical foundation for vocational education, where authentic project-based learning enables students to integrate vocational knowledge with practical innovation skills. Rather than emphasizing technical knowledge alone, vocational programs should provide structured opportunities for students to participate in iterative design thinking processes. These findings validate DTIR as a hierarchical framework for assessing innovation readiness through integrated competencies. The instrument also provides educators with a practical tool for diagnosing students' readiness and supporting targeted instruction, curriculum improvement, and innovation-oriented learning.

4. CONCLUSION

This study developed and validated the hierarchical DTIR model for vocational education, confirming that innovation readiness is an integrated construct comprising awareness, attitudes, cognitive processes, and practical skills. The second-order CFA supports DTIR as a valid framework for assessing students' readiness for design thinking–based innovation. The instrument offers practical value for diagnosing innovation readiness, informing targeted instruction, and evaluating innovation-oriented curricula. Limitations include the specific vocational context, seaweed-based food innovation focus, and cross-sectional design. Future research should validate DTIR across broader educational settings and examine its association with innovation performance, entrepreneurial intention, and work readiness.

ACKNOWLEDGMENTS

The authors would like to express their greatest appreciation to BRIN for the financial support and facilities that allowed the completion of the research. The authors also thank the schools, teachers, and all respondents who participated in and contributed to the data collection process.

FUNDING INFORMATION

The research is funded and supported by the Board of National Research and Innovation (BRIN) of the Republic of Indonesia through the RIIM Kompetisi (RIIM Competition) scheme, numbers 105/IV/KS/07/2025 and U12/714/VII/2025.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ika Maryani	✓	✓		✓	✓	✓	✓	✓	✓		✓		✓	✓
Mustofa Ahda				✓		✓	✓			✓			✓	
Amalya Nurul Khairi	✓					✓	✓			✓			✓	
Handewi Purwati Saliem	✓	✓		✓		✓				✓		✓		
Hasan Djidu			✓		✓		✓			✓				

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that no conflicts of interest occurred in the implementation or the publication of the research.

INFORMED CONSENT

All participants provided informed consent before participation. They were informed of the study purpose, procedures, and their rights, including voluntary participation and confidentiality. No personally identifiable information was collected or disclosed, and all responses were used solely for research purposes.

ETHICAL APPROVAL

The research has attained ethical clearance from the Research Ethics Committee of Universitas Ahmad Dahlan, Indonesia, with Ethical Clearance number: REC-UAD/01/01/01-2026/028.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [IM]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

REFERENCES

[1] D. Henriksen, C. Richardson, and R. Mehta, "Design thinking: a creative approach to educational problems of practice," *Thinking Skills and Creativity*, vol. 26, pp. 140–153, Dec. 2017, doi: 10.1016/j.tsc.2017.10.001.

[2] P. Lewis, "Innovation, technician skills, and vocational education and training: connecting innovation systems and vocational education and training," *Journal of Vocational Education & Training*, vol. 77, no. 2, pp. 364–391, Mar. 2025, doi: 10.1080/13636820.2023.2215749.

[3] J. Liedtka, A. Sheikh, C. Gilmer, M. Kupetz, and L. Wilcox, "The use of design thinking in the U.S. Federal Government," *Public Performance & Management Review*, vol. 43, no. 1, pp. 157–179, Jan. 2020, doi: 10.1080/15309576.2019.1657916.

[4] K. Tschimmel, "Creativity, design and design thinking—a human-centred ménage à trois for innovation," in *Perspectives on Design II*, D. Raposo, J. Neves, and J. Silva, Eds., Cham: Springer International Publishing, 2022, pp. 3–17, doi: 10.1007/978-3-030-79879-6_1.

[5] S. A. Yirga and M. A. Beshir, "The effect of total quality management practices on innovation: evidence from selected agricultural technical and vocational education training colleges in Ethiopia," *Journal of Innovation and Entrepreneurship*, vol. 14, no. 1, p. 21, Feb. 2025, doi: 10.1186/s13731-024-00460-x.

[6] F. Huang, "Exploring a new model of undergraduate vocational education," *Vocation, Technology & Education*, vol. 2, no. 1, pp. 1–12, Mar. 2025, doi: 10.54844/vte.2025.0869.

[7] M. A. Shahat, S. M. Al-Balushi, K. Al Alawi, K. Al Bahri, and J. Seikkula-Leino, "Fostering entrepreneurial mindsets and future skills: innovative educational units for enhancing creative problem-solving in tenth-grade students," *Thinking Skills and Creativity*, vol. 60, p. 102084, Jun. 2026, doi: 10.1016/j.tsc.2025.102084.

[8] H. Zuo, M. Zhang, and W. Huang, "Lifelong learning in vocational education: a game-theoretical exploration of innovation, entrepreneurial spirit, and strategic challenges," *Journal of Innovation & Knowledge*, vol. 10, no. 3, p. 100694, May 2025, doi: 10.1016/j.jik.2025.100694.

[9] Agusman and S. Wibowo, "Elemental composition of *Eucheuma cottonii* and *Gracillaria* sp. using scanning electron microscope-energy dispersive spectroscopic analysis," in *IOP Conference Series: Earth and Environmental Science*, vol. 733, no. 1, p. 012111, 2021, doi: 10.1088/1755-1315/733/1/012111.

[10] J. Debbarma, P. Viji, B. M. Rao, and C. N. Ravishankar, "Seaweeds: potential applications of the aquatic vegetables to augment nutritional composition, texture, and health benefits of food and food products," in *Sustainable Global Resources of Seaweeds Volume 2: Food, Pharmaceutical and Health Applications*, A. R. Rao and G. A. Ravishankar, Eds., Cham: Springer International Publishing, 2022, pp. 3–54, doi: 10.1007/978-3-030-92174-3_1.

[11] N. Mohammadi and N. Ostovar, "From sea to sweet: seaweed's role in nutritious and sustainable confectionery," *Comprehensive Reviews in Food Science and Food Safety*, vol. 25, no. 1, p. e70361, 2026, doi: 10.1111/1541-4337.70361.

[12] M. J. Blikra *et al.*, "Seaweed products for the future: using current tools to develop a sustainable food industry," *Trends in Food Science & Technology*, vol. 118, pp. 765–776, Dec. 2021, doi: 10.1016/j.tifs.2021.11.002.

[13] L. Pereira, J. Cotas, and A. Gonçalves, "Seaweed proteins: a step towards sustainability?" *Nutrients*, vol. 16, no. 8, p. 1123, Apr. 2024, doi: 10.3390/nu16081123.

[14] A. Billah, M. A. Rahman, and M. T. bin Hossain, "Factors influencing Muslim and non-Muslim consumers' consumption behavior: a case study on halal food," *Journal of Foodservice Business Research*, vol. 23, no. 4, pp. 324–349, Jul. 2020, doi: 10.1080/15378020.2020.1768040.

[15] P. Micheli, S. J. S. Wilner, S. H. Bhatti, M. Mura, and M. B. Beverland, "Doing design thinking: conceptual review, synthesis, and research agenda," *Journal of Product Innovation Management*, vol. 36, no. 2, pp. 124–148, Mar. 2019, doi: 10.1111/jpim.12466.

[16] V. Prikshat, S. Kumar, and A. Nankervis, "Work-readiness integrated competence model," *Education + Training*, vol. 61, no. 5, pp. 568–589, Jun. 2019, doi: 10.1108/ET-05-2018-0114.

[17] J. F. Hair, W. C. Black, B. J. Babin, and R. E. Anderson, *Multivariate data analysis*, 8th ed. Andover, U.K.: Cengage, 2019.

[18] D. Henriksen, L. J. Woo, and P. Mishra, "Working with constraints: creativity through repurposing," in *Exploring Perspectives on Creativity Theory and Research in Education*, Switzerland: Springer, 2024, pp. 3–22, doi: 10.1007/978-3-031-55416-2_1.

[19] I. Vanany, J. M. Soon, A. Maryani, and B. M. Wibawa, "Determinants of halal-food consumption in Indonesia," *Journal of Islamic Marketing*, vol. 11, no. 2, pp. 507–521, Mar. 2020, doi: 10.1108/JIMA-09-2018-0177.

[20] R. I. Elseidi, "Determinants of halal purchasing intentions: evidences from UK," *Journal of Islamic Marketing*, vol. 9, no. 1, pp. 167–190, Mar. 2018, doi: 10.1108/JIMA-02-2016-0013.

[21] L. E. Vila, P. J. Pérez, and V. Coll-Serrano, "Innovation at the workplace: do professional competencies matter?" *Journal of Business Research*, vol. 67, no. 5, pp. 752–757, May 2014, doi: 10.1016/j.jbusres.2013.11.039.

[22] J. Liedtka, "Innovative ways companies are using design thinking," *Strategy & Leadership*, vol. 42, no. 2, pp. 40–45, Mar. 2014, doi: 10.1108/SL-01-2014-0004.

[23] M. Krügel, "Innovative teaching in food product development and entrepreneurship for student success," in *Innovative Pedagogies for Entrepreneurship Education: Insights and Reflections from South Africa*, T. van der Westhuizen, Ed., Cham: Springer Nature Switzerland, 2026, pp. 263–286, doi: 10.1007/978-3-032-07204-7_13.

[24] D. Mufidah and M. Hanif, "Implementation of vocational life skills program to strengthen skills education," *Thawalib: Jurnal Kependidikan Islam*, vol. 6, no. 1, pp. 165–180, Apr. 2025, doi: 10.54150/thawalib.v6i1.643.

[25] O. Friborg, M. Martinussen, and J. H. Rosenvinge, "Likert-based vs. semantic differential-based scorings of positive psychological constructs: a psychometric comparison of two versions of a scale measuring resilience," *Personality and Individual Differences*, vol. 40, no. 5, pp. 873–884, Apr. 2006, doi: 10.1016/j.paid.2005.08.015.

[26] L. Hu and P. M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives," *Structural Equation Modeling: A Multidisciplinary Journal*, vol. 6, no. 1, pp. 1–55, Jan. 1999, doi: 10.1080/10705519909540118.

[27] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of Marketing Research*, vol. 18, no. 1, pp. 39–50, Feb. 1981, doi: 10.1177/002224378101800104.

[28] T. Tang, V. Vezzani, and V. Eriksson, "Developing critical thinking, collective creativity skills and problem solving through playful design jams," *Thinking Skills and Creativity*, vol. 37, p. 100696, Sep. 2020, doi: 10.1016/j.tsc.2020.100696.

[29] S. R. Velu, "Design thinking approach for increasing innovative action in universities: ICT's mediating effect," *Sustainability*, vol. 15, no. 1, p. 24, Dec. 2022, doi: 10.3390/su15010024.

[30] A. Kumar *et al.*, "Exploitation of seaweed functionality for the development of food products," *Food and Bioprocess Technology*, vol. 16, no. 9, pp. 1873–1903, Sep. 2023, doi: 10.1007/s11947-023-03023-2.

[31] J. Aschemann-Witzel, D. Asioli, M. Banovic, M. A. Perito, A. O. Peschel, and V. Stancu, "Defining upcycled food: the dual role of upcycling in reducing food loss and waste," *Trends in Food Science & Technology*, vol. 132, pp. 132–137, Feb. 2023, doi: 10.1016/j.tifs.2023.01.001.

[32] K. G. Grunert and S. Hieke, "Nudging for more sustainable and healthy food choices: a dual-processing approach with a time perspective," in *The Elgar Companion to Consumer Behaviour and the Sustainable Development Goals*, L. A. Reisch and C. R. Sunstein, Eds., Cheltenham, U.K.: Edward Elgar Publishing, 2025, pp. 191–204, doi: 10.4337/9781035325061.00022.
[33] S. Mekala, "Incorporating innovative thinking in twenty-first-century pedagogical practices," in *Thinking Skills in Higher Education*, S. Mekala and M. P. Shabitha, Eds., Singapore: Springer Nature Singapore, 2025, pp. 19–33, doi: 10.1007/978-981-96-5600-4_2.

BIOGRAPHIES OF AUTHORS

Ika Maryani is an associate professor at Universitas Ahmad Dahlan. She holds a doctoral degree in Science Education from Universitas Negeri Yogyakarta. Her research focuses on educational innovation, STEM education, curriculum development, and science learning, with recent interests in integrating IoT and AI in education. She has published extensively in academic journals and authored numerous scholarly books. She can be contacted at email: ika.maryani@uad.ac.id; ika_mail87@ymail.com.

Mustofa Ahda is an assistant professor at Universitas Ahmad Dahlan. He earned his PhD in Pharmacy from the International Islamic University of Malaysia. His expertise includes analytical chemistry, halal analysis, and food analysis. He currently serves as Head of the Ahmad Dahlan Halal Center and has published in reputable international journals. He can be contacted at email: mustofa.ahda@pharm.uad.ac.id.

Amalya Nurul Khairi is a lecturer in Food Technology at Universitas Ahmad Dahlan. She holds a master's degree from Universitas Gadjah Mada and has international research experience in Japan. Her research focuses on bioactive compounds and food processing, particularly from aquatic resources. She is also active as a halal auditor and journal reviewer. She can be contacted at email: amalya.khairi@tp.uad.ac.id.

Handewi Purwati Saliem is a senior researcher at BRIN. She earned her PhD in Agricultural Economics from Institut Pertanian Bogor. Her expertise includes food policy, food security, and environmental economics. She has produced over 140 scientific publications and contributed to national and international policy initiatives. She can be contacted at email: hand009@brin.go.id.

Hasan Djidu is a lecturer in Mathematics Education at Universitas Sembilanbelas November Kolaka. His research focuses on educational measurement, computational thinking, and assessment models such as Item Response Theory and machine learning-based classification. He can be contacted at email: hasandjidu@gmail.com.