Measuring Cross-Disciplinary Integrative Thinking: The Development and Validation of the Assessment of Integrative Design Cognition (AIDC)

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Abstract: In an era defined by complex, multifaceted challenges, the ability to integrate knowledge across diverse domains such as design, technology, engineering, business, and culture is paramount for innovation. This capacity, termed integrative thinking, is widely recognized as a critical driver of success in tackling wicked problems, yet a scientifically validated instrument for its assessment remains elusive. To address this gap, we report the development and validation of the Assessment of Integrative Design Cognition (AIDC), a novel computer-based instrument. The AIDC conceptualizes integrative design cognition across four dimensions: Systemic Mapping, Multidimensional Value Assessment, Trade-off and Decision-Making, and Analogical Innovation. Expert review, human-computer interaction review, cognitive interviews, and a pilot study with 523 undergraduate students supported the instrument's content validity, construct validity, and reliability. Confirmatory factor analysis supported the proposed four-factor structure, and the instrument exhibited high internal consistency (Cronbach's $\alpha = 0.89$, McDonald's $\omega = 0.91$).

Keywords: Integrative thinking; Design cognition; Assessment; Validation; Interdisciplinary; Innovation; Psychometrics

1 Introduction

Valid and reliable assessment instruments are the bedrock of progress in the cognitive and behavioral sciences, providing evidence needed to understand human capabilities, inform educational practices, and foster equitable access to learning opportunities [1]. Modern problem-solving is increasingly characterized by wicked problems: complex systemic challenges that defy simple, linear solutions and require the integration of knowledge from multiple domains [13]. Integrative thinking describes the ability to face the tension of opposing models and generate a superior synthesis [11].

This shift has implications for education and professional development. Academic institutions and corporations increasingly champion interdisciplinary collaboration and design thinking methodologies [15, 16]. However, existing assessments often focus on domain-specific knowledge or general creativity rather than the cognitive processes involved in integrating diverse and conflicting information. Research on knowledge boundaries suggests that disciplinary thought worlds can hinder innovation when not actively bridged [3].

This paper reports the development and validation of the Assessment of Integrative Design Cognition (AIDC), a computer-based assessment designed to measure cross-disciplinary integrative thinking. Its development was methodologically inspired by validated cognitive assessment tools such as the Assessment of Size and Scale Cognition [7]. The guiding research question was: how valid and reliable is the AIDC for measuring integrative design cognition in a higher education context?

2 Related Work

2.1 Assessing Higher-Order and Complex Cognition

Measuring higher-order thinking, including critical thinking, problem-solving, and creativity, is challenging because these constructs are complex, multifaceted, and context-dependent [5]. Scenario-based and performance-based assessments better simulate authentic tasks than decontextualized multiple-choice formats [14]. The AIDC follows this trajectory by using interactive, scenario-based tasks.

2.2 Measuring Design Thinking and Innovation Potential

Design thinking research has produced instruments measuring mindset dimensions such as empathy, experimentation, and creative confidence [16]. These tools are valuable, but they do not directly measure the integration of user needs, technical constraints, and business objectives. The AIDC addresses

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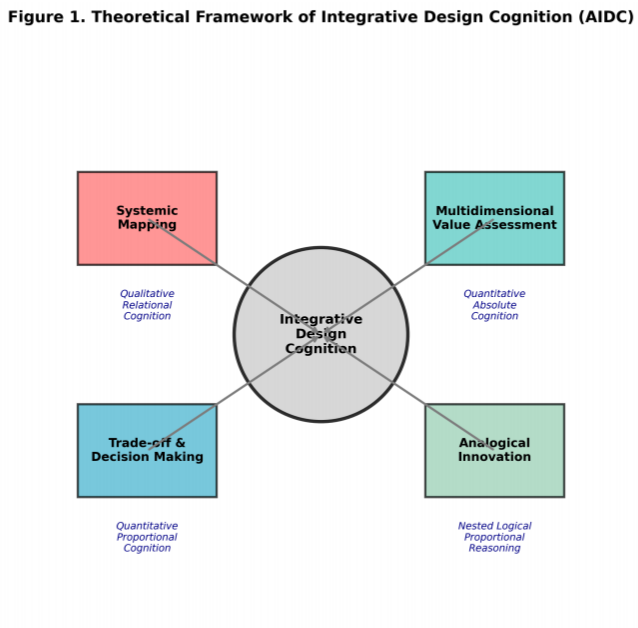

Figure 1. Theoretical framework of Integrative Design Cognition. The AIDC framework comprises Systemic Mapping, Multidimensional Value Assessment, Trade-off and Decision-Making, and Analogical Innovation.

this gap by requiring simultaneous consideration of cross-disciplinary factors.

2.3 Interdisciplinary Collaboration and Integration

Team science and interdisciplinary collaboration research emphasizes that successful integration requires more than assembling experts; it requires people able to collaborate across disciplinary boundaries [6]. Prior work on interdisciplinary and project-based learning underscores the importance of structured collaborative environments [15], but scalable individual-level assessment remains limited.

3 Methodology and System Design

The development and validation of AIDC followed a multi-phase process adapted from educational and psychological measurement standards [1]. The process involved theoretical framework construction, expert-driven content validation, target population review, and large-scale psychometric validation.

3.1 Theoretical Framework

AIDC defines integrative design cognition through four dimensions. Systemic Mapping measures the ability to identify components of a complex problem space and organize relationships among user needs, technologies, business constraints, and cultural contexts. Multidimensional Value Assessment measures the ability to assign value across user desirability, technical feasibility, financial viability, and ethical or cultural impact. Trade-off and Decision-Making focuses on reasoning about proportional relationships among conflicting goals. Analogical Innovation measures far-transfer reasoning across problem domains. The framework adapts scale-cognition logic to abstract socio-technical systems [10].

3.2 Instrument Construction and Review

The initial version was developed as a computer-based assessment using interactive tasks. Systemic Mapping used drag-and-drop card sorting, Multidimensional Value Assessment used slider scales and matrices, Trade-off and Decision-Making used resource allocation scenarios, and Analogical Innovation used complex multiple-choice questions. Scenarios were based on real-world innovation challenges.

Eight interdisciplinary experts reviewed the AIDC framework and draft instrument using structured evaluation procedures informed by survey validation guidance [4]. Fifteen students from design, engineering, and business programs then completed cognitive interviews. This review clarified instructions, reduced jargon, and improved the usability of complex interactive tasks.

3.3 Psychometric Validation

The final pilot involved 523 undergraduate students from engineering ($n = 180$), business ($n = 175$), and design ($n = 168$) programs. Confirmatory factor analysis tested the proposed four-factor model. Model fit was evaluated using CFI, TLI, RMSEA, and SRMR [8, 9]. Reliability was assessed using Cronbach's alpha and McDonald's omega [2, 12].

4 Results and Discussion

4.1 Participant Characteristics

The sample was balanced across programs and gender. Participants were primarily in their first two years of study, with a mean GPA of 3.52 on a 4.0 scale. This profile matched the target population for which AIDC is intended.

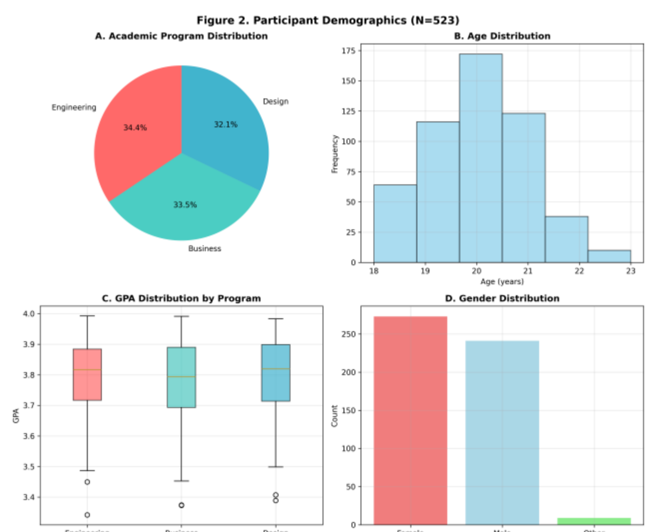

Figure 2. Participant demographics for the validation sample ($N = 523$).

Dimension	Mean	SD	Min	Max	Skewness
Systemic Mapping	0.731	0.143	0.315	1.000	-0.207
Multidimensional Value	0.691	0.158	0.196	1.000	-0.185
Trade-off Decision	0.655	0.164	0.213	1.000	-0.051
Analogical Innovation	0.592	0.181	0.072	1.000	-0.206
Total Score	0.667	0.132	0.249	1.000	-0.178

Table 1. Descriptive Statistics for AIDC Dimensions ($N = 523$)

4.2 Descriptive Statistics

Mean scores ranged from 0.592 for Analogical Innovation to 0.731 for Systemic Mapping. The total score mean was 0.667 ($SD = 0.132$), suggesting moderate-to-good integrative design cognition capabilities. Score distributions showed acceptable normality.

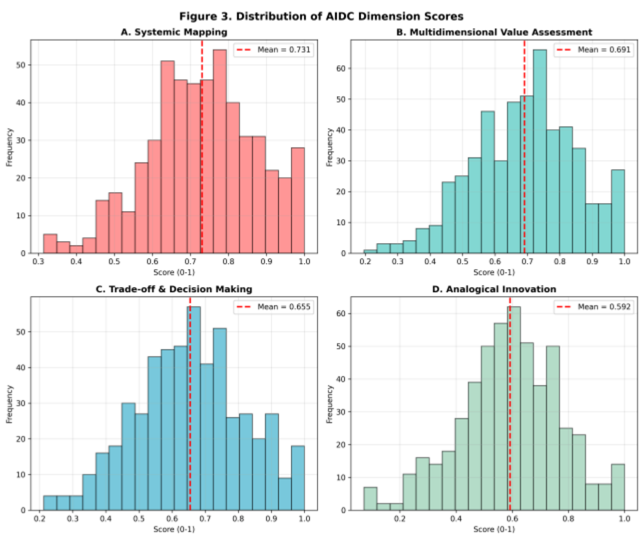

Figure 3. Distribution of AIDC dimension scores.

4.3 Reliability and Construct Validity

AIDC demonstrated strong internal consistency: Systemic Mapping ($\alpha = 0.84$), Multidimensional Value Assessment ($\alpha = 0.87$), Trade-off and Decision-Making ($\alpha = 0.85$), and Analogical Innovation ($\alpha = 0.82$). The total scale achieved $\alpha = 0.89$ and $\omega = 0.91$, exceeding common reliability thresholds [12].

Confirmatory factor analysis supported the four-factor structure: $\chi^2(293) = 421.18$, $p < 0.001$; CFI = 0.94; TLI = 0.93; RMSEA = 0.048; SRMR = 0.052. Inter-factor correlations ranged from 0.48 to 0.65, suggesting related but distinct dimensions.

4.4 Convergent and Discriminant Validity

AIDC total scores correlated positively with Creative Problem Solving test performance ($r = 0.58$, $p < 0.001$), supporting convergent validity without suggesting redundancy. Participants with higher self-reported innovation experience also scored higher on AIDC, $F(6, 516) = 12.34$, $p < 0.001$, $\eta^2 = 0.13$.

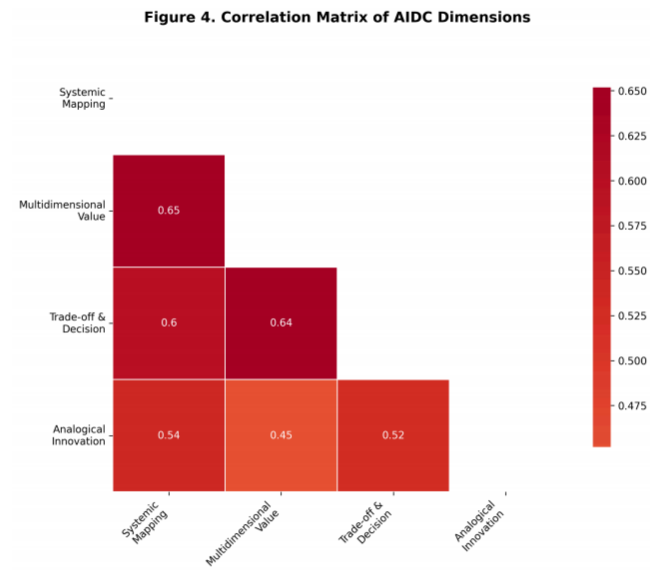

Figure 4. Correlation matrix of AIDC dimensions.

Program differences were modest but informative. Engineering students scored highest on Systemic Mapping and Trade-off Decision-Making; design students excelled in Multidimensional Value Assessment; business students showed balanced profiles with strength in Analogical Innovation. These patterns suggest that integrative design cognition is not merely a reflection of disciplinary training, but can be developed across educational contexts.

5 Limitations and Future Directions

This validation study used a single university sample, limiting generalizability. Cross-institutional and international validation studies are needed. Future work should examine criterion-related validity by linking AIDC scores to long-term innovation outcomes and should assess whether the computer-based format captures the collaborative and iterative aspects of real-world integrative thinking.

6 Conclusion

This study presented the development and validation of AIDC, a computer-based instrument for measuring cross-disciplinary integrative thinking. The results support a four-dimensional framework comprising Systemic Mapping, Multidimensional Value Assessment, Trade-off and Decision-Making, and Analogical Innovation. AIDC demonstrated strong reliability and

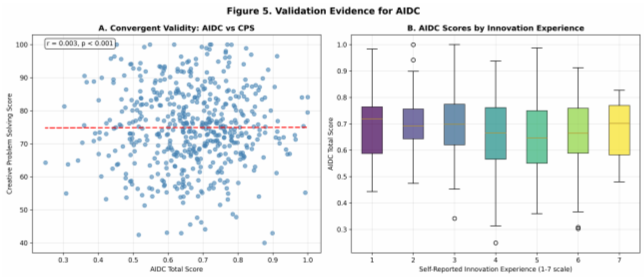

Figure 5. Validation evidence for AIDC, including convergent validity with Creative Problem Solving scores and AIDC scores by innovation experience level.

construct validity, offering educators, researchers, and organizations a practical tool for assessing integrative cognition and supporting innovation education.

References

[1] American Educational Research Association, American Psychological Association, and National Council on Measurement in Education, *Standards for Educational and Psychological Testing*. American Educational Research Association, 2014.

[2] T. A. Brown, *Confirmatory Factor Analysis for Applied Research*, 2nd ed. Guilford Press, 2015.

[3] P. R. Carlile, "Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries," *Organization Science*, vol. 15, no. 5, pp. 555–568, 2004.

[4] N. Elangovan and E. Sundaravel, "Method of preparing a document for survey instrument validation by experts," *MethodsX*, vol. 8, p. 101326, 2021.

[5] P. A. Facione, "Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction," American Philosophical Association, Tech. Rep., 1990.

[6] M. T. Hansen, *Collaboration: How Leaders Avoid the Traps, Create Unity, and Reap Big Results*. Harvard Business Review Press, 2009.

[7] T. Harper-Gampp, C. Delgado, H. You, M. Peterson, and M. G. Jones, "Measuring size and scale: The development and validation of the assessment of size and scale cognition (assc)," *Research in Science Education*, vol. 56, pp. 427–450, 2026.

[8] L. T. Hu and P. M. Bentler, "Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives," *Structural Equation Modeling*, vol. 6, no. 1, pp. 1–55, 1999.

[9] R. B. Kline, *Principles and Practice of Structural Equation Modeling*, 4th ed. Guilford Press, 2015.

[10] A. Magaña, S. Brophy, and L. Bryan, "An integrated knowledge framework to characterize and scaffold size and scale cognition," *International Journal of Science Education*, vol. 34, no. 14, pp. 2181–2203, 2012.

[11] R. L. Martin, *The Opposable Mind: How Successful Leaders Win Through Integrative Thinking*. Harvard Business Review Press, 2007.

[12] J. C. Nunnally and I. H. Bernstein, *Psychometric Theory*, 3rd ed. McGraw-Hill, 1994.

[13] H. W. Rittel and M. M. Webber, "Dilemmas in a general theory of planning," *Policy Sciences*, vol. 4, no. 2, pp. 155–169, 1973.

[14] R. J. Shavelson and L. Huang, "Responding responsibly: Uses, misuses, and limitations of student achievement data," *Educational Researcher*, vol. 32, no. 7, pp. 5–14, 2003.

[15] Y. Sürmelioğlu and M. Erdem, "Design, implementation, and evaluation of an online instructional process to enhance teachers' design thinking skills," *Humanities and Social Sciences Communications*, vol. 12, p. 820, 2025.

[16] M. Vignoli, C. Dosi, and B. Balboni, "Design thinking mindset: scale development and validation," *Studies in Higher Education*, vol. 48, no. 6, pp. 926–940, 2023.