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Construction of a Competency-Based Assessment Tool for Microstructural Analysis in Practical Metallurgical (CAT-M)

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ABSTRACT

The Metallurgy Laboratory course emphasizes learning outcomes in microstructural analysis and heat-treatment processes; however, existing assessments rely predominantly on knowledge tests and lack comprehensive tools for evaluating practical skills and professional attributes. This limitation restricts students from identifying their competency levels and hinders effective learning development. To address this gap, the present study developed and validated the Competency-Based Assessment Tool for Microstructural Analysis (CAT-M) to provide a comprehensive evaluation of student performance in practical metallurgy. The study involved 30 third-year students enrolled in the Industrial Education Program at King Mongkut's University of Technology Thonburi during the second semester of the 2023 academic year. CAT-M comprises three components: a multiple-choice knowledge test, a rubric-based practical skill assessment, and a behavioural rating scale that assesses responsibility, discipline, and safety awareness. Content validity was examined using the Item-Objective Congruence (IOC) method, while test quality was evaluated through item analysis and reliability indices. IOC values ranged from 0.67 to 1.00. The knowledge test demonstrated item difficulty ranging from 0.20 to 1.00, with discrimination indices of 0.20–1.00 (pre-test) and 0.00–1.00 (post-test). Reliability indices were acceptable, with KR-20 values of 1.12 (pre-test) and 1.19 (post-test), and Cronbach's alpha coefficients of 0.63 and 0.53. The rubric and behavioural scale also demonstrated acceptable validity with IOC values above 0.50. The findings indicate that CAT-M is a valid, structured, and appropriate instrument for assessing knowledge, skills, and attributes. By integrating multiple domains, CAT-M enhances evaluation practices, supports student self-awareness, and strengthens competency-based curriculum development in technical and vocational education.

Keywords: *Competency-Based Assessment Tool for Microstructural Analysis (CAT-M); microstructural analysis; practical metallurgy; technical education; performance evaluation*

1. Introduction

The development trajectory of Thailand's steel industry differs from that of many other countries. Rather than progressing from upstream to downstream, the sector began with downstream processes such as rebar mills and pipe manufacturing plants, before gradually expanding into midstream production through electric arc furnaces and mini-mills. This was later followed by investment in other finished steel products [1]. Since Thailand transitioned to a newly industrialized country and during its rapid growth as one of the "Asian Tigers," the application and demand for metals, particularly steel, have evolved significantly. Today, under increasing pressure to adopt advanced technologies and reduce costs, the Thai steel industry continues to advance rapidly. These developments have been supported by substantial improvements in metallurgical knowledge compared to two decades ago, though variations in steel demand across construction, automotive, electrical, and machinery still create challenges and opportunities for innovation [2].

Within this context, the Bachelor of Industrial Education Program in Industrial Engineering (five-year program) emphasizes competency-based education that integrates theoretical knowledge with practical experience. The Metallurgy Laboratory course is central to achieving program-level learning outcomes, requiring students to analyze the microstructure of ferrous and non-ferrous materials, demonstrate laboratory skills, and explain the influence of hardening parameters on mechanical properties. Consistent with outcome-based education (OBE) principles, the course emphasizes assessment of both cognitive and psychomotor competencies. Therefore, developing valid and reliable competency-based assessment tools is essential to ensure instructional quality and provide evidence of student achievement.

Competency encompasses integrating knowledge, skills, and attributes required for effective performance in professional roles [3,4]. In engineering education, competencies extend beyond technical expertise, including values, ethics, responsibility, and workplace behaviors [5,6]. However, in the Metallurgy Laboratory course, existing assessments focus predominantly on knowledge, often neglecting practical skills and professional attributes. Student feedback from course PTE 352 at King Mongkut's University of Technology Thonburi indicated uncertainty regarding evaluation criteria, leaving students unable to determine their competency levels or identify areas for improvement [7]. Previous research demonstrates that diverse tools such as written exams, simulations, interviews, and project evaluations can support competency development [8]. Nonetheless, a pressing need remains to develop comprehensive assessment tools tailored to practical metallurgy, ensuring accurate evaluation and supporting learner-centered instructional approaches.

The research objectives are to examine the quality of the competency assessment tool for evaluating knowledge, skill, and desirable attributes in microstructural analysis in practical metallurgy.

1.1 Theoretical Framework

This research is grounded in a review of theoretical principles and related studies concerning the content of the Metallurgy Laboratory course, particularly focusing on microstructural analysis in practical metallurgy. The theoretical framework includes the following key components.

1.1.1 Concepts and theories of competency

Competency refers to integrating knowledge, skills, and attributes required to perform specific tasks effectively [9]. In engineering education, competencies are aligned with technical expertise and soft skills, ensuring learners can function efficiently in real-world scenarios.

1.1.2 Learning theories related to microstructural analysis

Constructivist learning theory posits that learners build knowledge through active engagement and contextual experiences [10,11]. In metallurgy, this involves laboratory-based learning, metallographic preparation, and interpretation of microstructures through microscopes and heat treatment experiments.

1.1.3 Assessment and measurement theories

Assessment theories such as classical test theory (CTT) and item response theory (IRT) are foundational in ensuring the validity, reliability, and fairness of educational measurements [12]. These frameworks support the development of high-quality performance-based instruments.

1.1.4 Theories of academic achievement

Bloom's Taxonomy provides a hierarchy for cognitive learning objectives ranging from knowledge, recall, to evaluation and creation [13,14]. This taxonomy guides the development of this research's learning outcomes and assessment tools.

1.1.5 Performance-based and practical skill assessment

Authentic assessment practices emphasize real-world performance tasks. Performance assessments should reflect the complexity of tasks students will face in their future careers, thus requiring observation, execution, and judgment [15].

1.1.6 Theories of desirable attributes

As defined by Krathwohl et al. [16], the affective domain includes values, attitudes, and emotional responses. In practical metallurgy, desirable attributes include safety awareness, responsibility, precision, and teamwork (Table 1).

1.1.7 Instrument quality evaluation methods

The quality of the assessment tools was examined through content validity (using expert judgment), reliability (e.g., Cronbach's alpha), and item analysis (difficulty and discrimination indices), in accordance with guidelines by Crocker and Algina [17]. These methods ensure the assessment tools are psychometrically sound and educationally meaningful.

Table 1: Research variables in Competency-Based Assessment Tool for Microstructural Analysis (CAT-M)

Variable Type	Variable
Independent Variables	Competency assessment on microstructural analysis in practical metallurgy, consisting of: • Knowledge, Skill, and desirable attributes assessment tool on microstructural analysis.
Dependent Variables	Quality of the competency assessment tools, consisting of: • Knowledge, Skill, and Desirable Attributes Assessment Tool.

2. Methodology

2.1 Identification of Target Groups Relevant to the Study

2.1.1 Population

The population of this study was undergraduate students majoring in Industrial Engineering, Department of Industrial Education, Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi, enrolled in the second semester of the academic year 2023 [18].

2.1.2 Sample group

The sample consisted of 30 third-year students from the same program and institution as the population. All had completed the course "Metallurgy Laboratory (PTE 352)" during the second semester of the academic year 2023. The sample was selected using purposive sampling to conduct item difficulty and discrimination analyses [18].

2.1.3 Subject-matter Experts

Subject-matter experts were selected to evaluate the content validity of the competency assessment tools for microstructural analysis in practical metallurgy, specifically the knowledge and skill components. These experts held at least a master's degree in industrial engineering and had at least five years of relevant professional experience. Purposive sampling was employed to select these experts.

2.1.4 Measurement and evaluation experts

Measurement experts were engaged to assess the content validity of the tools measuring desirable attributes in practical metallurgy and the satisfaction questionnaire regarding the assessment tools. These experts held at least a master's degree in either Industrial Engineering or Educational Measurement and Evaluation, and had at least five years of experience in relevant fields. Purposive sampling was used in their selection.

2.2 Study Instruments Used in the Research Project

The research project employed the following instruments.

2.2.1 Competency assessment tool for knowledge

This is related to microstructural analysis in practical metallurgy. This instrument was designed to evaluate students' theoretical understanding of microstructural characteristics, metallurgical principles, and analytical procedures applied during laboratory practices.

2.2.2 Competency assessment tool for skills

This is applied in microstructural analysis in practical metallurgy. This tool measured students' technical proficiency and performance in conducting metallographic procedures, including sample preparation, microscope operation, and interpretation of microstructures.

2.2.3 Competency assessment tool for desirable attributes

This was evaluated in the context of microstructural analysis in practical metallurgy. This instrument assessed learners' work habits, responsibility, attention to detail, and compliance with laboratory safety and professional standards during practical sessions.

2.3 Design and Development of Research Instruments

A knowledge-based competency assessment tool for microstructural analysis in practical metallurgy was constructed in Table 2.

Table 2: Design and Quality Analysis of the Knowledge-Based Competency Assessment Tool

Component	Description
Item Types	• Objective-type items: Multiple-choice (five options), requiring selecting the most appropriate/correct answer. • Subjective-type items: Constructed response questions.
Cognitive Levels (based on intended learning outcomes in microstructural analysis)	• Recall (R) – ability to correctly identify microstructural features. • Application (A) – ability to correctly analyse microstructures. • Analysis (An) – ability to explain the relationship between microstructure and mechanical properties.
Content Validity Verification	Three subject-matter experts evaluated the content validity. The Item-Objective Congruence (IOC) index was applied as an indicator [19].
Test Quality Analysis	• Item Difficulty Index (P): Acceptable range = 0.20–0.80. • Item Discrimination Index (D): Acceptable value = ≥ 0.20. • Reliability Measures: KR-21 formula and Cronbach's alpha.

A skill-based competency assessment tool for microstructural analysis in practical metallurgy was designed, as shown in Table 3.

Table 3: Design and Quality Analysis of the Skill-Based Competency Assessment Tool

Component	Description
Development of the Skill Assessment Tool	The instrument was designed using a rating scale format with a scoring rubric comprising five performance levels: • 4 = Excellent • 3 = Good • 2 = Fair • 1 = Poor • 0 = Not Demonstrated Assessment was based on task-specific performance criteria.
Content Validity Verification	Subject-matter experts reviewed the tool to determine alignment with intended outcomes. The Item-Objective Congruence (IOC) index was applied as an indicator [20].
Inter-Rater Reliability Assessment	Reliability was assessed by having multiple raters independently evaluate the same performances. Consistency among raters was analysed using Kappa statistics and the standard error of measurement [21].

2.3.1 Desirable Attributes-Based Competency Assessment Tool for Microstructural Analysis

The assessment tool was designed based on the desirable graduate characteristics as defined by King Mongkut's University of Technology Thonburi (KMUTT), aligned with Thailand's National Qualifications Framework for Higher Education [22]. The attributes assessed include Knowledge, Skills, Ethics, and Character. Checklist items were scored dichotomously (achieved/not achieved).

2.3.2 Implementation of the Assessment Tools

The developed assessment tools were pilot-tested with a sample of third-year students majoring in Industrial Engineering, Department of Industrial Education, Faculty of Industrial Education and Technology, King Mongkut's University of Technology Thonburi (KMUTT), during the second semester of the 2023 academic year. A total of 30 students who had completed the course PTE 352: Metallurgy Laboratory participated in the trial.

The trial was conducted by three researchers, who also facilitated the administration of the tools and recorded performance data for evaluation and refinement of the instruments. Summary of Research Instrument Design is shown in Table 4.

Table 4: Summary of Research Instrument Design in Competency-Based Assessment Tool for Microstructural Analysis (CAT-M)

Assessment Tool	Development Focus	Validation Methods	Quality Analysis
Knowledge-Based Competency	Objective and Subjective tests based on 3 cognitive levels: Recall, Application, Analysis	IOC Index by 3 experts	Difficulty Index (0.20-0.80), Discrimination Index (>0.20), KR-21, Cronbach's Alpha
Skill-Based Competency	Rating scale with scoring rubric (5 levels: 4 to 0) based on performance criteria	IOC Index by experts	Inter-Rater Reliability, Kappa Statistics, Standard Error
Desirable Attributes-Based Competency	Checklist format aligned with KMUTT and Thailand NQF (Knowledge, Skills, Ethics, Character)	IOC Index based on behavioural indicators	Binary scoring (Achieved/Not Achieved)

3. Results and Discussion

The Quality of the Competency Assessment Tools for Microstructure Analysis in Practical Metallurgy is summarized in Table 5.

Table 5: Quality of the Competency Assessment Tools for Microstructure Analysis in Practical Metallurgy

Assessment Tool	Evaluation Criteria	Results
Knowledge Competency	Content Validity	All 7 items had an Index of Item-Objective Congruence (IOC) ≥ 0.50 (3 experts).
	Item Difficulty & Discrimination	Difficulty indices ranged from 0.20 to 1.00; 4 items met quality criteria, 1 item required revision.
	Reliability (Pre-test)	Mean = 2.84, S.D. = 1.88, KR-20 = 1.12, Cronbach's alpha = 0.63 (High reliability).
	Reliability (Post-test)	Mean = 7.84, S.D. = 4.77, KR-20 = 1.19, Cronbach's alpha = 0.53 (Low reliability).
Skill Competency	Content Validity	All 6 items had IOC ≥ 0.50 (3 experts).
Desirable Characteristics Competency	Content Validity	All 10 items had IOC ≥ 0.50 (3 experts).

3.1 Knowledge Competency Assessment

This assessment tool consisted of five multiple-choice items (five-option objective test) and two short-answer (subjective) items. The learning outcomes covered five levels of cognitive behaviour, with a passing threshold set at level 3 or above. The reliability analysis of the pre-instruction test indicated high reliability, while the post-instruction version demonstrated a lower reliability and required further improvement.

3.1.1 Content validity

Three experts examined the content validity of the knowledge competency assessment tools for microstructure analysis in practical metallurgy (pre-test and post-test). All seven test items received an Index of Item-Objective Congruence (IOC) score of 0.50 or higher, indicating acceptable content validity for all items.

3.1.2 Item difficulty, discrimination, and quality

An item analysis was conducted on five multiple-choice questions administered to 30 participants. The difficulty indices ranged from 0.20 to 1.00. Four items met the quality standards based on established criteria, while one required revision.

3.1.3 Reliability

The analysis of the pre-test results revealed a mean score ($\bar{x}$) of 2.84 with a standard deviation (S.D.) of 1.88. The reliability indices indicated acceptable consistency, with a KR-20 value of 1.12 and a Cronbach's alpha coefficient of 0.63, which falls within the acceptable range of $0.60–1.00$. These findings suggest that the pre-test demonstrated a relatively high level of reliability. In contrast, the post-test results showed a mean score ($\bar{x}$) of 7.84 with a standard deviation (S.D.) of 4.77. The KR-20 value was 1.19, while Cronbach's alpha was 0.53, below the acceptable threshold. This indicates that the post-test exhibited a lower reliability level than the pre-test.

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3.2 Skill competency assessment

This assessment tool used a rating scale of six subjective test items, evaluated using a scoring rubric with five levels: 4, 3, 2, 1, and 0. The evaluation was based on a rubric-based performance scoring system. A competency level of 3 or above was considered acceptable.

3.2.1 Content validity

Three experts evaluated the content validity of the skill competency assessment tools. All six items received IOC values of 0.50 or above, demonstrating that all items were suitable for use.

3.2.2 Desirable attributes Competency Assessment

Checklist of 10 behavioural indicators scored dichotomously. IOC values were ≥0.50. Competency at level 3 or higher was sufficient.

The development of the competency assessment tool for microstructural analysis in practical metallurgy provides an essential framework that enables students to recognize and reflect on their performance in three key domains: knowledge, practical skills, and desirable attributes. The study revealed that the knowledge-based assessment was applicable and functionally effective. This finding aligns with the note that "assessment is the process of assigning numerical values or symbols to represent learner characteristics or observable behaviours."[23]. Regarding practical skills assessment, the study used two instruments. Practical competencies in microstructural analysis were evaluated using two instruments. A dichotomous performance observation checklist proved functional and valid, reflecting desirable attributes as expected behaviours recognized by others [21]. In addition, a five-level rubric (4–0), consistent with the Dreyfus Model of Skill Acquisition, provided a structured framework for classifying expertise from Novice to Expert. These instruments offered a dependable and theoretically grounded approach for assessing student performance. Standardized performance expectations also guided the assessment of desirable attributes. The rubric scoring followed a binary format and reflected the national qualifications framework (NQF), which emphasizes integrating knowledge, skills, ethics, and character [22]. These developments showed that the tools were applicable for measuring students' competency in microstructural analysis in a practical metallurgy context. The instruments effectively captured cognitive, psychomotor, and affective learning outcomes and can be further utilized to improve instructional design and student assessment practices. However, the discrepancy between KR-20 (1.19) and α (0.53) highlights test limitations. High KR-20 may reflect score imbalance, while low α suggests weak inter-item correlation. Causes include small sample size, limited sample, and low discrimination. Improvements should involve revising/expanding items, balancing difficulty, increasing sample size, and employing complementary reliability methods.

4. Conclusion

The development of CAT-M resulted in a three-part framework to assess cognitive, psychomotor, and affective competencies. The knowledge-based tool showed acceptable pre-instruction reliability but lower post-instruction reliability. The skill-based rubric proved effective and had strong validity, while the attributes checklist was confirmed as suitable for evaluating professional traits. These findings align with Bloom's Taxonomy, the Dreyfus Model, and Thailand's NQF, ensuring academic and practical relevance. The study contributes to technical and vocational education by providing an evidence-based tool for outcome-based learning. Comparable research by Obe et al. [24] and Ahmad & Rofiq [25] highlights the importance of multi-domain assessment in aligning training with industry needs. Furthermore, the reliability discrepancy observed here supports concerns raised by Tan [26] on the limitations of KR-20 and α. Future research should expand samples, refine items, and apply Item Response Theory (IRT) to improve tool reliability and applicability.

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