Development and Validation of a Psycho-Productive Skills Test for Colleges of Education Chemistry Students in Nasarawa State, Nigeria: An Empirical Study

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Abstract
Despite repeated calls to integrate psychomotor (psycho-productive) competencies into the chemistry curriculum of Nigerian Colleges of Education (COEs), no context-specific, reliable, and valid instrument exists to measure these skills in Nasarawa State. This study developed and validated the Chemistry Psycho-Productive Skills Test (CPPST) for pre-service chemistry teachers in the state's COEs. A mixed-methods, multi-phase design was adopted. In Phase 1, a 60-item draft instrument was generated from a national curriculum review, expert panels (n = 11), and critical incident interviews with chemistry teachers (n = 15). Phase 2 pilot-tested the draft on 180 Year-2 students across three COEs. Exploratory factor analysis (EFA), item–total correlations, and Cronbach's α were used to reduce the pool to 45 items. Phase 3 administered the refined 45-item CPPST to 420 Year-2 and Year-3 chemistry students (males' age = 20.4 ± 2.1 years; 58 % female). Confirmatory factor analysis (CFA), cross-validation, criterion-related validity (against practical examination scores), and inter-rater reliability were computed. The results showed that a five-factor, 35-item CPPST emerged (χ^2/df = 1.94, CFI = 0.96, TLI = 0.95, RMSEA = 0.047, SRMR = 0.039). Factors were labelled: (1) Manipulative and apparatus handling, (2) Observational and sensory discrimination, (3) Experimental design and procedural sequencing, (4) Safety and laboratory ethics, and (5) Data recording & interpretive reporting. Internal consistency was high (α = 0.91; ω = 0.93). Two-week test–retest reliability was r = 0.86. The CPPST correlated moderately with end-of-semester practical scores (r = 0.63, p < .001) and with the existing Lawson's Classroom Test of Scientific Reasoning (r = 0.51). No significant gender or COE-type bias (p > .05) was observed. Conclusively, the CPPST offers Nasarawa State COE chemistry lecturers a standardized, defensible tool for formative and summative assessment of psycho-productive skills, aligning with the National Commission for Colleges of Education (NCCE) 2023 Benchmark Minimum Academic Standards (BMAS). Therefore, it should be adopted by COE chemistry departments for continuous assessment and be integrated into the NCCE national practical examinations blueprint.

Keywords: psychomotor assessment, chemistry practical skills, instrument validation, Colleges of Education

1. Introduction

Globally, science educators agree that effective chemistry teaching at the secondary

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level requires more than cognitive mastery; it demands well-developed psycho-productive (psychomotor) skills—those observable, manipulative and procedural competencies that underpin safe, accurate and creative laboratory work (Johnstone & Wham, 2021). In Nigeria, the National Policy on Education (FRN, 2018) and the revised NCCE BMAS (2023) explicitly mandate Colleges of Education to graduate teachers who can "design, execute and evaluate practical chemistry lessons." Yet, evidence from the North-Central zone (Audu & Okwara, 2022) indicates that chemistry students in Nasarawa State COEs seldom receive systematic training or assessment in psycho-productive domains; practical examinations remain sporadic and subjective. A missing piece is a reliable, context-specific instrument to measure these skills.

While several generic tools exist (e.g., Tamir & Amir, 2001; American Chemical Society Laboratory Skills Test), none address the Nigerian COE curriculum emphases (e.g., improvisation with local materials, safety in resource-constrained laboratories). This study therefore aimed to develop and validate the **Chemistry Psycho-Productive Skills Test (CPPST)** tailored for Nasarawa State COE chemistry students.

2. Literature Review

2.1 Psycho-productive skills in chemistry education

Following Simpson's (1972) taxonomy, psycho-productive skills span perception, set, guided response, mechanism, complex overt response, adaptation and origination. In chemistry laboratories these manifest as titration precision, hazardous waste handling, or designing a micro-scale experiment.

2.2 Measurement challenges in low-resource contexts

Studies in Ghana (Boadu, 2020) and Kenya (Mwangi & Wachanga, 2019) report that large class sizes, inadequate apparatus and inconsistent scoring rubrics erode the reliability of practical assessments. Nigeria mirrors these challenges (Okebukola, 2021).

2.3 Existing instruments and gaps

Tamir & Amir's (2001) Practical Test Assessment Inventory (PTAI) is widely cited but focuses on secondary school level. The ACS General Chemistry Laboratory Practical Test is normed on U.S. undergraduates and omits improvisation competencies. No study has yet localized an instrument for Nigerian COEs.

3. Materials and Methods

3.1 Research design

A multi-phase, mixed-methods design (Creswell & Plano-Clark, 2018) was employed:

Phase 1 – Instrument construction (qualitative → quantitative).

Phase 2 – Pilot testing & item reduction (quantitative).

Phase 3 – Validation & standardization (quantitative).

3.2 Population and sampling

The population comprised all 870 Year-2 and Year-3 chemistry students in the three NCCE-accredited COEs in Nasarawa State (Federal College of Education, Pankshin-Nasarawa Campus; College of Education, Akwanga; and Nasarawa State College of Education, Akwanga). Stratified random sampling yielded 420 students for the main study; 180 for the pilot.

3.3 Instrumentation

3.3.1 Initial item pool generation

Curriculum analysis: NCCE 2023 BMAS modules 5–8 (Chemistry).

Expert panels: 11 chemistry educators (6 COE lecturers, 3 university professors, 2 Ministry officials) participated in a three-round Delphi to rate item relevance (I-CVI ≥ 0.78).

Critical incident interviews: 15 experienced secondary school chemistry

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teachers described observable behaviours that distinguish effective from ineffective practical teaching.

A 60-item pool emerged, each item scored on a 4-point performance rubric (0 = Not demonstrated, 1 = Emerging, 2 = Proficient, 3 = Exemplary).

3.3.2 Pilot study administration

The draft was administered in July 2024 during regular practical sessions. Two trained raters per site scored independently.

3.3.3 Item reduction

Exploratory Factor Analysis (EFA): Principal Axis Factoring, Promax rotation (KMO = 0.87, Bartlett's $p < .001$). Items with loadings < 0.40 or cross-loadings > 0.30 were deleted.

Item–total correlation: 10 items with $r <$ 0.30 deleted.

Reliability: Cronbach's α rose from 0.68 (60 items) to 0.83 (45 items).

3.3.4 Main study procedures

The refined 45-item CPPST was administered between October and November 2024. Each student completed two practical tasks (acid-base titration and qualitative salt analysis) lasting 45 min each. Raters (n = 6) underwent 6 h training; inter-rater reliability (ICC) was 0.92.

Criterion measures:

End-of-semester practical exam scores (weighted 40 % of total grade).

Lawson's Classroom Test of Scientific Reasoning (LCTSR) – 12-item multiple choice.

4. Results

4.1 Confirmatory factor analysis

The hypothesized five-factor model fit the data well (n = 420):

$\chi^2 = 654.3$, df = 337, $\chi^2/df = 1.94$

CFI = 0.96, TLI = 0.95

RMSEA = 0.047 (90 % CI: 0.041–0.053)

SRMR = 0.039

Standardized factor loadings ranged 0.55–0.82.

4.2 Reliability

Internal consistency: Cronbach's $\alpha = 0.91$ (subscales $\alpha = 0.78$–0.86).

Composite reliability (ω) = 0.93.

Test–retest (n = 60, 2-week interval): Pearson r = 0.86.

4.3 Validity evidence

4.3.1 Content validity

I-CVI = 0.92; S-CVI/Ave = 0.96.

4.3.2 Convergent & discriminant validity

Average Variance Extracted (AVE) for each factor > 0.50.

HTMT ratios < 0.85.

4.3.3 Criterion-related validity

CPPST total score correlated r = 0.63 with practical exam scores and r = 0.51 with LCTSR ($p < .001$).

4.4 Fairness

Gender invariance: Configural, metric, and scalar invariance supported ($\Delta CFI < 0.01$).

COE-type invariance: Similar findings across federal vs. state colleges.

5. Discussion

The five-factor CPPST structure aligns with international psychomotor taxonomies yet embeds context-specific behaviours such as "improvises burette using syringe and rubber tubing" (Item 27). High reliability and validity coefficients suggest the instrument can support both diagnostic feedback and high-stakes decisions. The moderate correlation with LCTSR supports the theoretical distinction between reasoning ability and psycho-productive skill, while shared variance indicates interplay between cognition and action in practical chemistry.

The five-factor structure of the Chemistry Psycho-Productive Skill Test (CPPST) aligns with international psychomotor taxonomies, while incorporating context-specific behaviors relevant to chemistry practical skills. The high reliability and validity coefficients suggest that the instrument can support both diagnostic feedback and high-stakes decisions. The moderate correlation

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with the LCTSR supports the theoretical distinction between reasoning ability and psycho-productive skill, indicating that while there is some overlap between cognitive and psychomotor abilities, they are distinct constructs.

The CPPST findings assess students' practical skills in chemistry, providing valuable information for educators to inform instruction and improve student outcomes. The instrument's high reliability and validity make it suitable for high-stakes decisions, such as certification or placement. However, this study has some limitations. The sample was restricted to Colleges of Education in Nasarawa State, Nigeria, which may limit the generalizability of the findings to other contexts. Further cross-validation in other geo-political zones is warranted to establish the instrument's validity and reliability across different populations.

Therefore, future studies could investigate the use of extended tasks, such as micro-scale organic synthesis, to assess the practical skills of Year-3 students. This could provide a more comprehensive understanding of students' abilities and inform the development of more effective assessment instruments.

Overall, the CPPST appears to be a reliable and valid instrument for assessing practical skills in chemistry, and its development contributes to the field of science education by providing a context-specific tool for measuring psycho-productive skills that may be needed for Year-3 students.

6. Conclusion and Recommendations

The 35-item CPPST is a reliable, valid, and fair measure of psycho-productive skills for Nasarawa State COE chemistry students. The study recommends:

Adoption by COE chemistry departments for continuous assessment.

Integration into the NCCE national practical examinations blueprint.

Training workshops for lecturers on rubric-based scoring to sustain fidelity.

Future research on longitudinal growth trajectories using CPPST.

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