

Development of Heat & Thermodynamics Achievement Test (HTAT) Based on Revised Bloom's Taxonomy of Educational Objectives

Dr. R. Senthil Kumar

Assistant Professor, Department of Curriculum Planning and Evaluation, TNTEU, Chennai, Tamil Nadu, India

Abstract: This paper reports the systematic development and validation of the Heat & Thermodynamics Achievement Test (HTAT) for higher secondary (Class 11) physics students studying under Tamil Nadu state board syllabus. It was done as part of a study to investigate the effectiveness of jigsaw cooperative learning on the academic achievement of class 11 students in physics. The HTAT was designed to measure student learning across six cognitive domains of the Revised Bloom's Taxonomy (Remembering, Understanding, Applying, Analyzing, Evaluating, and Creating) for the unit Heat & Thermodynamics. Instrument construction followed a four-stage process: blueprinting, item writing, expert validation, and empirical pilot testing ($N = 60$). Classical item analysis and internal consistency estimates (Cronbach's alpha) were conducted and construct validity was explored using exploratory factor analysis. Results indicate that the HTAT contains 44 well-behaved items (balanced across cognitive levels and content sub-topics), with acceptable reliability ($\alpha = .80$), appropriate item difficulty ($.3 < p < .7$) & discrimination value ($D \geq .4$), and a coherent factor structure reflecting major content aspects. The HTAT is presented as a valid, reliable, and practical tool for classroom assessment and research on learning interventions in heat and thermodynamics unit of class 11 Physics.

Keywords: Revised Bloom's Taxonomy, cognitive levels, Physics, Heat and Thermodynamics, higher secondary, achievement test

1. Introduction

'Assessment drives instruction': valid, reliable instruments are essential for diagnosing misconceptions, measuring academic achievement, and evaluating pedagogical innovations. The topic of Heat & Thermodynamics (H&T) is conceptually rich and frequently reported as cognitively-challenging for senior secondary learners of Indian boards. Despite many classroom assessments in physics, there is a shortage of standardized, taxonomy-aligned tools that explicitly sample cognitive complexity according to the Revised Bloom's Taxonomy (RBT) of Educational Objectives (Anderson et al., 2001). This study is aimed to develop the *Heat & Thermodynamics Achievement Test (HTAT)*—an objective, curriculum-aligned instrument mapping items to RBT levels and to common subtopics (heat & temperature, gas laws, thermal properties, laws of heat transfer, laws of thermodynamics, thermodynamic processes, and heat engine & Carnot cycle) given under the Tamil Nadu state board syllabus (Department of School Education, 2023).

2. Method

2.1 Instrument design principles and blueprint

A test blueprint was created linking content area (7 subtopics) with the six RBT cognitive levels. The target length was 40 items to balance breadth and administration time (≈ 45 – 50 minutes). Item distribution followed instructional emphasis and Bloom coverage: Remembering (9), Understanding (8), Applying (8), Analyzing (6), Evaluating (6), Creating (3). Item format was multiple-choice (four options) for objective scoring.

2.2 Item writing and review

An initial pool of 77 items was authored in consultation with subject-matter experts, an educational measurement expert, and a language expert. Items were written to a clear stem—options standard, avoiding ambiguous language and cueing. Distractors were grounded in known student misconceptions (e.g., temperature vs heat confusion, pressure–temperature relations in gases).

2.3 Content validation

Five domain experts (senior physics teachers and university lecturers) evaluated items for relevance and alignment using a 3-point scale (essential, useful but not essential, not necessary). Content Validity Ratio (CVR) was computed (Pennington, 2003) for each item (items with CVR below the threshold (based on panel size) were revised or removed. Additionally, an overall Content Validity Index (CVI) at the test level was calculated.

2.4 Pilot administration and sample

The revised pool (55 items) was pilot tested with 60 Class 11 students drawn from two different schools representing different socio-academic contexts. Standardized administration procedures were followed. Demographic information (age, prior achievement indicator) was collected to examine differential item performance.

3. Analysis

3.1 Classical item analysis

Item difficulty (p -value) and discrimination (upper–lower index D) statistics were computed. Criteria: retain items with $0.30 < p < 0.70$ and $D \geq 0.40$; items outside these

ranges were reviewed for content or key errors or ultimately rejected (Kline, 1986).

3.2 Reliability

Internal consistency was estimated using Cronbach's alpha (Cronbach, 1951) where rubrics generated polytomous scoring. A reliability threshold of $\geq .70$ was used for acceptable classroom measures.

3.3 Construct validity

Exploratory factor analysis (EFA, principal axis factoring with oblique rotation) was used to inspect latent structure (Fabrigar, & Wegener, 2012). Parallel analysis and Scree plot informed number of factors. Convergent validity checks compared HTAT scores with a course end-term score (where available).

4. Results

4.1 Item reduction and final form

From the 55 piloted items, only the items that met psychometric criteria, and expert judgment were retained for the final HTAT scored with analytic rubrics. The final cognitive distribution closely matched the blueprint.

4.2 Item statistics

Mean item difficulty $p_{\text{mean}} = .49$ ($\sigma = .12$) and a mean discrimination index $D_{\text{mean}} = .44$ ($\sigma = .09$). Only five items were marginal (D between .18–.20) and flagged for future revision.

4.3 Reliability and validity

Cronbach's alpha including polytomous responses $\alpha = .80$. EFA suggested a 3-factor solution broadly corresponding to (a) Fundamental concepts & measurement (temperature, scales, gas laws, entropy), (b) Energy & heat processes (specific heat, calorimetry, latent heat, thermodynamic processes, Meyers' relation), and (c) Thermal phenomena & applications (expansion, heat transfer, Newton's cooling). These factors align with content structure and support construct validity. HTAT total scores correlated moderately with course end-term grades ($r = .63$), indicating concurrent validity.

5. Discussion

The HTAT demonstrates sound psychometric properties for classroom and research use. The explicit mapping to Revised Bloom's Taxonomy ensures that the instrument samples cognitive complexity rather than merely factual recall. High reliability ($\alpha = .80$) and satisfactory item discrimination suggest the HTAT is sensitive to student differences in H&T understanding. Factor structure reflects plausible content clusters, supporting the argument that the test measures coherent dimensions of thermodynamics knowledge.

Practically, the HTAT can be used for (1) diagnostic pre-testing to identify misconceptions, (2) evaluating instructional interventions (e.g., Jigsaw, inquiry-based labs), and (3) formative assessment with item-level feedback to guide remediation. The inclusion of higher-order items (Analyze/Evaluate/Create) encourages teachers to design instruction targeting deeper cognitive engagement.

5.1 Limitations

Several limitations warrant mention. The pilot sample, while adequate for initial validation ($N = 60$), was geographically limited; broader sampling across states and boards would strengthen generalizability. EFA provides preliminary construct insights but confirmatory factor analysis (CFA) on an independent sample is recommended. Also, the test's language and context were aligned to the local curriculum; minor adaptation may be necessary for other syllabi or age cohorts.

5.2 Implications and future work

Future efforts should (a) collect normative data by grade and board to enable standard score reporting, (b) perform DIF (Differential Item Functioning) analyses to check fairness across gender and socio-economic groups, and (c) run longitudinal studies to examine HTAT sensitivity to instruction over time. Additionally, converting selected items into computer-adaptive formats could improve efficiency and precision.

6. Conclusion

The HTAT, developed through a rigorous blueprinting, expert validation, and empirical pilot process, is a practically useful and psychometrically acceptable measure of student learning in Heat & Thermodynamics that explicitly maps to the Revised Bloom's Taxonomy. It fills a gap for instructors and researchers who need an objective, taxonomy-aligned instrument to measure both surface and deep learning in this challenging physics domain.

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Contact: For copies of the HTAT, scoring rubrics/key, or raw anonymized data, please contact the author.

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Appendix I

Blueprint

No.	Content area / sub-topics	Revised Bloom's taxonomy – Cognitive levels						No. of items	%
		Remember	Understand	Apply	Analyze	Evaluate	Create		
1	Heat & Temperature	1	2	1	1			5	11%
2	Gas laws	2	1	1	1	1	1	7	16%
3	Thermal properties	1	2		2	1		6	14%
4	Laws of heat transfer	1	1	1	2			5	11%
5	Laws of thermodynamics	3	1	1	1	1	1	8	18%
6	Thermodynamic processes	2	1	2	1	1	1	8	18%
7	Heat engine – Carnot cycle	2	1	1	1			5	11%
No. of items		12	9	7	9	4	3	44	
%		27%	20%	16%	20%	9%	7%		
Order of Thinking Skills (OTS)		(Lower) LOTS (63%)			(Higher) HOTS (36%)				