

Implementation of Certainty Factor Method in a Web-Based Expert System for Abacus Student Level Assessment

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Abstract

The placement of new students into appropriate program levels is a critical factor in the effectiveness of mental arithmetic education through the abacus method. At SEMPOA SIP Binjai Mas, this process has historically been conducted manually, relying heavily on the subjective intuition of instructors, which often results in inconsistent decision-making and assessment bias. Furthermore, the inherent uncertainty in student performance during diagnostic tests often caused by nervousness or incomplete understanding further complicates accurate classification. This research aims to design and implement a web-based expert system using the Certainty Factor (CF) method to provide a standardized, objective, and mathematically grounded recommendation for student placement. The system was developed using the Waterfall methodology and utilizes 11 validated capability indicators to categorize students into two primary levels: *Junior* and *Foundation*. The Certainty Factor method was specifically employed to quantify uncertainty and manage the degrees of confidence in student performance by integrating expert knowledge (MB and MD values) with user-provided observations. Empirical validation through a case study demonstrated high precision, yielding a 99.73% confidence level for program placement in a scenario where manual assessment might prove ambiguous. Black-box testing further confirmed that all system functionalities are 100% valid and meet operational requirements. The implementation of this expert system significantly mitigates assessment subjectivity, enhances administrative efficiency through real-time data access, and establishes a transparent, professional assessment framework for the institution.

Keywords: Expert System, Certainty Factor, Abacus Education, Student Placement, Web-based Application.

1. Introduction

Abacus-based mental arithmetic education serves as a crucial educational investment in optimizing the balance between left- and right-brain cognitive functions in early childhood [1]. Within the abacus learning framework, accurate initial level placement forms the core foundation for aligning instructional materials with a student's cognitive development. However, in practice, level determination across tutoring institutions remains heavily dependent on manual evaluation, relying on instructors' qualitative observations and subjective intuition [2]. This conventional approach suffers from fundamental limitations, notably high susceptibility to inter-instructor perceptual bias, which results in inconsistent and subjective placement decisions [3]. This operational bottleneck is further compounded by a total reliance on senior instructors to physically validate each assessment, causing administrative delays and significantly reducing operational efficiency [4].

Assessment complexity increases further when accounting for data uncertainty in prospective students' responses. Young learners frequently exhibit unstable performance indicators caused by internal hesitation, low confidence, or test anxiety [5]; [2]). Analyzing such complex and dynamic evaluation data requires robust computational techniques capable of objective information processing, analogous to how Natural Language Processing (NLP) and Deep Learning handle unstructured data to extract valuable insights [6]. In the context of qualitative and imprecise skill evaluation, expert system technology offers a rule-based computational solution that formalizes human reasoning into standardized decision criteria [7]; [8].

To quantify uncertainty and student response hesitation precisely, the Certainty Factor (CF) method presents an adaptive and effective quantitative approach [9]. The CF method evaluates expert belief levels by calculating a Measure of Belief (MB) and a Measure of Disbelief (MD). Combining these two parameters converts qualitative indicators of student hesitation into a single, precise numerical certainty score. Although the Certainty Factor method has proven reliable in medical diagnosis and general academic tracking, its application in quantifying childhood response hesitation within abacus mental arithmetic placement remains under-explored in existing literature.

Integrating modern computational models also requires a flexible, accessible system infrastructure. Deploying an expert system within a web-based architecture ensures multi-platform accessibility, real-time data synchronization, and streamlined operational oversight for institution management [10]. Furthermore, a web-based deployment supports centralized, structured, and efficient digitization of student academic records [4].

To address this research gap, this study aims to design, implement, and evaluate a web-based expert system for abacus mental arithmetic placement using the Certainty Factor method. The primary novelty and contribution of this work lie in establishing a standardized digital evaluation model that mathematically models student response uncertainty. Consequently, this model minimizes instructor bias, reduces reliance on senior evaluators, and improves both administrative efficiency and placement accuracy overall.

2. Research Methodology

2.1. Research Stages

This study adopts the Waterfall software development lifecycle (SDLC) model, which provides a systematic, sequential, and structured framework for system engineering. The research workflow begins with problem identification to evaluate the operational limitations and subjective bias inherent in manual abacus level placement. This is followed by a literature review to examine core concepts of expert systems and the mathematical formulation of the Certainty Factor (CF) algorithm.

To construct the domain knowledge base, expert knowledge elicitation was conducted through field observations and in-depth interviews with senior abacus instructors. Subsequently, system requirements analysis was performed alongside the formal mathematical modeling of the CF decision logic. The system architecture, database scheme, and workflow were designed and subsequently implemented into a web-based application using PHP. Finally, the system underwent empirical validation using Black-Box testing to ensure functional correctness, system usability, and recommendation accuracy.

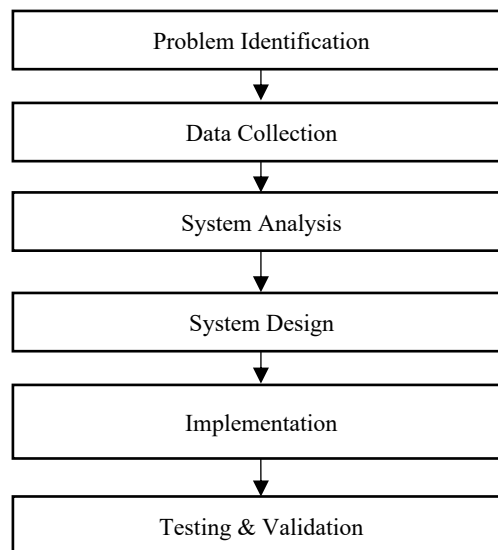


Fig 1: Research Stages

The sequential phases of the research methodology are detailed as follows:

1. Problem Identification: Investigating operational challenges and inter-instructor subjectivity in student placement at SEMPOA SIP Binjai Mas.
2. Data Collection: Conducting field observations and structured interviews with senior instructors acting as domain experts to gather rule criteria and certainty weights.
3. System Analysis: Formalizing the Certainty Factor calculation workflow and defining functional and non-functional software requirements.
4. System Design: Developing the software architecture, including system flowcharts, Unified Modeling Language (UML) diagrams, and the MySQL database schema.
5. Implementation: Translating software designs and CF decision logic into executable source code using PHP.
6. Testing and Validation: Executing Black-Box functional testing to verify feature performance, edge-case handling, and the numerical accuracy of placement recommendations.

2.2. System Architecture and Development Environment

Naïve Bayes is a fundamental classification algorithm based on probability principles and Bayes' Theorem. It predicts a data category by calculating the probability of a class occurrence based on its inherent features. The "naïve" aspect of the algorithm refers to the simplifying assumption that each feature in the data is independent. Despite this simplification, Naïve Bayes has proven to be highly efficient and reliable for handling large-scale text datasets with high feature dimensions [11].

2.3. System Architecture and Development Environment

The proposed expert system employs a web-based client-server architecture to optimize computational workload distribution [10]. The client layer provides an intuitive web browser user interface for data entry and result visualization. Meanwhile, the server layer handles business logic execution, database interactions, and the core Certainty Factor (CF) inference mechanisms. The software stack utilizes server-side PHP to execute rule-based reasoning procedures and MySQL as the Relational Database Management System (RDBMS) [12]. The MySQL database manages structured relational tables holding domain knowledge rules, expert confidence parameters, and historical evaluation logs.

2.4. Certainty Factor (CF) Formulation

The Certainty Factor (CF) method manages non-deterministic data resulting from student response hesitation during abacus placement testing [9]. The algorithm maps an expert's belief level regarding a specific hypothesis based on observed performance indicators.

2.5. Mathematical Foundation

The degree of certainty for a given hypothesis (h) influenced by an observed piece of evidence (e) is determined by multiplying the expert's subjective weight by the user's observed confidence score, as expressed in Equation (1):

$$CF[h,e] = CF[expert] \times CF[user] \quad [1]$$

Where:

- CF[h,e] : The calculated certainty factor for hypothesis h given evidence e.
 CF[expert] : The base confidence weight assigned by domain experts (MB-MD).
 CF[user] : The confidence weight derived from the student's actual performance Indicators

2.6. Sequential Evidence Combination

Because initial placement assessment evaluates multiple performance indicators simultaneously, the system combines individual CF values sequentially [13]. When two evaluated indicators yield positive certainty factors ($CF_1 > 0$ and $CF_2 > 0$), the cumulative certainty score ($CF_{combine}$) is calculated using Equation (2):

$$CF_{combine}(CF_1, CF_2) = CF_1 + CF_2 \times (1 - CF_1) \quad [2]$$

This combination process iterates across all identified evidence items until a final cumulative value (CF_{final}) is obtained. To facilitate straightforward interpretation for instructors and parents, (CF_{final}) is converted into a percentage using Equation (3):

$$\text{Certainty Percentage} = CF_{Final} \times 100\% \quad [3]$$

2.7. System Design and Database Scheme

Functional requirements are modeled using Unified Modeling Language (UML) Use Case diagrams, defining distinct privileges for System Administrators and Senior Instructors (e.g., managing the knowledge base, executing student assessments, and generating placement reports). The MySQL database schema relies on three foundational tables:

1. table_level: Stores target abacus curriculum levels and diagnostic thresholds.
2. table_indikator: Contains observable performance indicators and response traits.
3. table_relasi: Links indicators to respective placement levels, storing the domain expert weights (MB and MD).

3. Results and Discussion

3.1. Implementation of the Certainty Factor Algorithm

The implementation of the Certainty Factor (CF) algorithm within the expert system is executed via an inference engine that processes input performance indicators provided by the evaluator. The computational pipeline follows three primary sequential stages:

1. Indicator Weighting: For each detected indicator, the inference engine calculates the individual evidence certainty score by multiplying the expert's assigned weight CF_{expert} by the instructor's selected confidence score CF_{user} .
2. Sequential Evidence Combination: The system aggregates the individual certainty scores iteratively using the sequential combination formula until a cumulative final certainty factor CF_{final} is derived.
3. Score Normalization: The system converts the resulting decimal value into an absolute percentage score to simplify decision-making for instructors, administrative staff, and parents.
- 4.

Tabel 1: Skill Indicators, Target Level Relationships, and Expert CF Weights

Code	Skill Indicator (Evidence)	Expert CF (P1: Junior)	Expert CF (P2: Foundation)
G1	Mampu mengenal dan menyebut angka 1–10 secara tepat	0.8	0.4
G2	Mampu menyebutkan urutan angka maju 1–20	0.6	0.6
G3	Mampu melakukan penjumlahan sederhana ($hasil \leq 10$)	-	0.8
G4	Mampu melakukan pengurangan sederhana ($bilangan \leq 10$)	-	0.8
G5	Mampu memegang dan mengoperasikan sempoa dengan benar	-	0.8
G6	Mampu menggeser manik sempoa sesuai nilai angka 1–9	-	0.8
G7	Menunjukkan kesiapan belajar (fokus ± 15 menit)	0.8	0.6
G8	Mampu mengenal angka 1–100 secara tepat	-	0.8
G9	Menunjukkan konsentrasi yang baik saat berhitung	0.6	0.8

Code	Skill Indicator (Evidence)	Expert CF (P1: Junior)	Expert CF (P2: Foundation)
G10	Memiliki kemampuan berhitung cepat secara mental	-	-
G11	Memiliki riwayat mengikuti kursus sempoa sebelumnya	-	0.9

3.2. Case Analysis and Mathematical Verification

To validate the computational integrity of the inference engine, a diagnostic test case was conducted using real-world evaluation data from a prospective student (Ananda Budi, age 6) at SEMPOA SIP Binjai Mas. The diagnostic evaluation evaluated initial placement between Level P1 (Junior) and Level P2 (Foundation). Table 2 details the observed performance indicators and corresponding user confidence values (CF_{user}).

Table 2: Observed Skill Indicators for Evaluation Case (Subject: Ananda Budi)

No	Code	Skill Indicator Description	Evaluator Response	CF User
1	G1	Mampu mengenal angka 1–10 secara tepat	Pasti (P)	1,0
2	G2	Mampu menyebutkan urutan angka maju 1–20	Pasti (P)	1,0
3	G3	Mampu melakukan penjumlahan sederhana	Pasti (P)	1,0
4	G4	Mampu melakukan pengurangan sederhana	Yakin (Y)	0,6
5	G7	Menunjukkan kesiapan belajar (fokus)	Pasti (P)	1,0
6	G8	Mampu mengenal angka 1–100 secara tepat	Yakin (Y)	0,6
7	G9	Menunjukkan konsentrasi baik saat berhitung	Yakin (Y)	0,6

3.2.1 Detailed Mathematical Walkthrough

A. Certainty Factor Calculation for Level P1 (Junior)

The active indicators mapped to Level P1 are G1, G2, G7, and G9:

$$CF_1(G1) = CF_{expert} \times CF_{user} = 0.8 \times 1.0 = 0.80$$

$$CF_2(G2) = CF_{expert} \times CF_{user} = 0.6 \times 1.0 = 0.60$$

$$CF_3(G7) = CF_{expert} \times CF_{user} = 0.8 \times 1.0 = 0.80$$

$$CF_4(G9) = CF_{expert} \times CF_{user} = 0.6 \times 0.6 = 0.36$$

Sequential Combination:

$$CF_{combine1}(CF_1, CF_2) = 0.80 + 0.60 \times (1 - 0.80) = 0.9200$$

$$CF_{combine2}(CF_{combine1}, CF_3) = 0.9200 + 0.80 \times (1 - 0.9200) = 0.9840$$

$$CF_{combine3}(CF_{combine2}, CF_4) = 0.9840 + 0.36 \times (1 - 0.9840) = (0.9898)$$

$$\text{Certainty Score } (P_1) = 0.9898 \times 100\% = (98.98\%)$$

B. Certainty Factor Calculation for Level P2 (Foundation)

The active indicators mapped to Level P2 are G1, G2, G3, G4, G7, G8, and G9:

$$CF_1(G1) = 0.4 \times 1.0 = 0.40$$

$$CF_2(G2) = 0.6 \times 1.0 = 0.60$$

$$CF_3(G3) = 0.8 \times 1.0 = 0.80$$

$$CF_4(G4) = 0.8 \times 0.6 = 0.48$$

$$CF_5(G7) = 0.6 \times 1.0 = 0.60$$

$$CF_6(G8) = 0.8 \times 0.6 = 0.48$$

$$CF_7(G9) = 0.8 \times 0.6 = 0.48$$

Sequential Combination:

$$CF_{c1}(CF_1, CF_2) = 0.40 + 0.60 \times (1 - 0.40) = 0.7600$$

$$CF_{c2}(CF_{c1}, CF_3) = 0.7600 + 0.80 \times (1 - 0.7600) = 0.9520$$

$$CF_{c3}(CF_{c2}, CF_4) = 0.9520 + 0.48 \times (1 - 0.9520) = 0.9750$$

$$CF_{c4}(CF_{c3}, CF_5) = 0.9750 + 0.60 \times (1 - 0.9750) = 0.9900$$

$$CF_{c5}(CF_{c4}, CF_6) = 0.9900 + 0.48 \times (1 - 0.9900) = 0.9948$$

$$CF_{c6}(CF_{c5}, CF_7) = 0.9948 + 0.48 \times (1 - 0.9948) = (0.9973)$$

$$\text{Certainty Score } (P_2) = 0.9973 \times 100\% = (99.73\%)$$

Table 3: Summary of Placement Calculations

Rank	Level Code	Program Level Name	Final CF Score	Confidence Percentage	Recommendation Status
1	P2	Foundation	0,9973	99,73%	Recommended
2	P1	Junior	0,9898	98,98%	Alternative

As summarized in Table 3, the system recommends placement in Level P2 (Foundation) with a confidence level of 99.73%. This recommendation is driven by the student's demonstrated competence in basic operational arithmetic skills (G4 and G8), which hold higher expert weights within the Level P2 curriculum framework.

3.3. User Interface (UI) Implementation

The web-based application was implemented using PHP and MySQL. Front-end interfaces were built using standard HTML5, CSS3, and JavaScript frameworks to ensure cross-device responsiveness across mobile and desktop browsers.

1. Landing Page (Home Interface)

Displays institution information, user guides, and navigation controls for evaluation modules and administrator authentication.



Fig 2: Home Interface

2. Skill Evaluation Module

A dynamic assessment form enabling instructors to evaluate indicators (G1–G11) and assign user certainty values (CFuser).

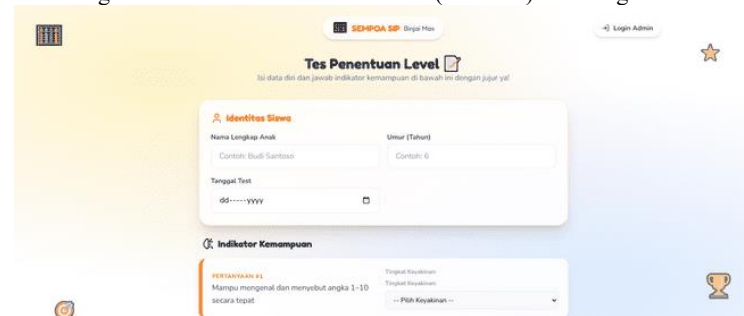


Fig 3: Skill Evaluation Module

3. Placement Result Dashboard

Renders final placement recommendations alongside maximum certainty percentages and step-by-step mathematical breakdowns.

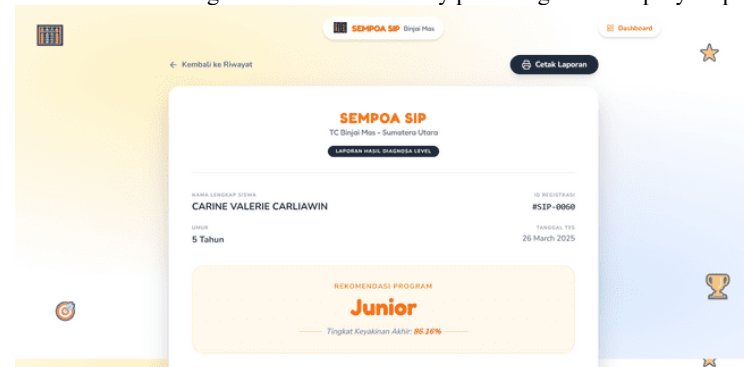


Fig 4: Placement Result Dashboard

4. Admin Knowledge Management Dashboard

Allows administrative management to update rules, adjust expert weight factors (CFexpert), and review diagnostic logs.

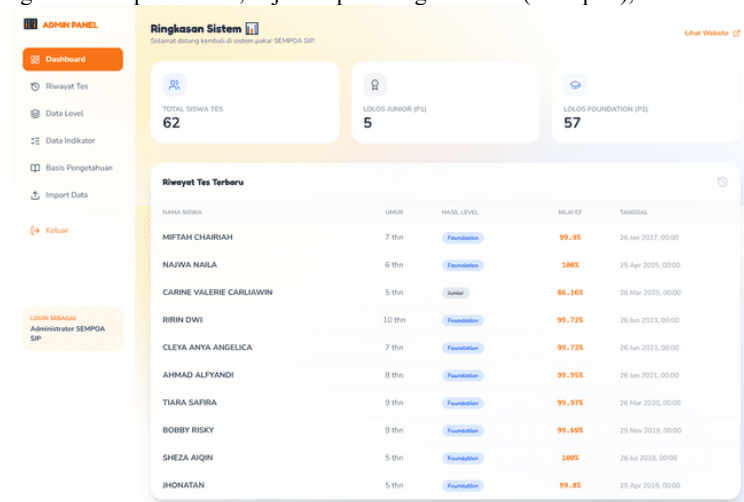


Fig 5: Admin Knowledge Management Dashboard

5. Security Authentication Panel

Secures control panel features via credential verification.

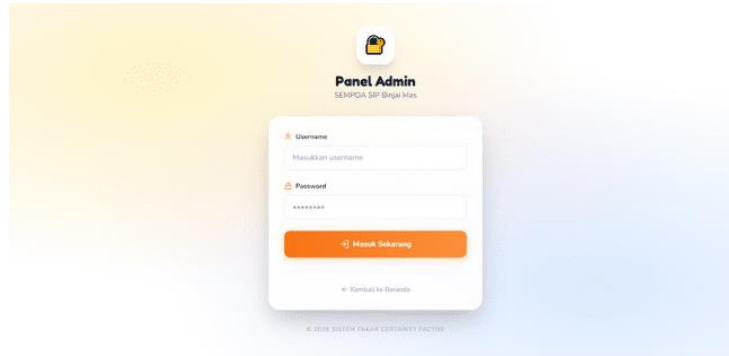


Fig 6: Security Authentication Panel

3.4. Software Functionality Testing (Black-Box Validation)

Black-Box testing validated the system's operational features against pre-defined functional requirements. Test cases evaluated user interface responses, database transactions, input boundary limits, and mathematical calculations.

Table 4: Black-Box Test Results

No	Functional Module / Feature	Test Objective / Expected Result	Status
1	Autentikasi Pengguna (<i>Login</i>)	Berhasil autentikasi sesuai hak akses (<i>role</i>).	Valid
2	Manajemen Data Indikator	Data tersinkronisasi dengan benar di MySQL.	Valid
3	Manajemen Basis Pengetahuan	Berhasil mengaitkan indikator dengan level.	Valid
4	Input Evaluasi Kemampuan	Sistem menerima masukan variabel <i>CF User</i> (0,0 - 1,0).	Valid
5	Eksekusi Perhitungan CF	Mesin inferensi menjalankan perhitungan secara akurat.	Valid
6	Output Rekomendasi Level	Menampilkan persentase keyakinan tertinggi.	Valid
7	Riwayat Hasil (<i>Log</i>)	Data diagnosis tersimpan otomatis di basis data.	Valid
8	Terminasi Sesi (<i>Logout</i>)	Sesi dihancurkan dan kembali ke halaman <i>login</i> .	Valid

4. Conclusion

This study successfully designed, implemented, and evaluated a web-based expert system utilizing PHP and MySQL that transforms traditional abacus placement testing into a standardized, digital, and objective workflow. By integrating the Certainty Factor (CF) algorithm across 11 key performance indicators (G1–G11), the system effectively quantifies student hesitation and mitigates subjective evaluator bias, converting qualitative observations into transparent, mathematically traceable certainty percentages. Empirical case testing verified the algorithmic reliability of the inference engine in accurately classifying student placement such as recommending Level P2 (Foundation) with a 99.73% certainty score thereby reducing misplacement risks associated with instructor fatigue or inconsistent judgment. Furthermore, comprehensive Black-Box testing validated that all system features function correctly, while the client-server web architecture ensures real-time data access, secure centralized record management, and improved operational efficiency.

5. Suggestion

To further extend the utility and operational scope of this expert system, several avenues for future work are recommended. First, expanding the knowledge base by incorporating additional diagnostic indicators and inference rules will allow the system to accommodate advanced mental arithmetic curriculum levels. Second, integrating this expert system directly into comprehensive School Management Information Systems (SMIS) can streamline related administrative tasks, such as online student enrollment and fee management. Third, establishing periodic calibration of expert confidence parameters (MB and MD) with senior instructors will ensure that the underlying rule base remains synchronized with modern pedagogical updates. Finally, developing a mobile or Progressive Web Application (PWA) would enable evaluators to input real-time observations directly from portable devices during live testing sessions.

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