Metacognition-Driven Approach to Enhance Computer Programming Skills: A Multi-Criteria Decision Making Analysis

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Abstract: Computer program writing is thought to be a challenging skill to master by both experts and students. A key component of developing into a successful student [1] of computer programming is metacognition. Instructive brain science defines metacognition as the monitoring and management of one's cognitive processes. 1145 engineering students were assessed using the personality questionnaires, Brain Dominance, Multiple Intelligences, Learning Style, and Metacognition tests. The two key elements of this study from Multiple Criteria Decision Making (MCDM) methods are the AHP and TOPSIS algorithms, which produce optimal decisions based on priorities. The multiple criteria decision-making process is compatible with both min and max functions. The study's psychology dataset includes four attributes for thinking style, eight for multiple intelligences, five for the personality scale, four for learning style, and eight for the metacognitive awareness inventory. The max function is also used for the learning style and the four attributes for the personality scale. The MCDM's outcome ranking order can be applied to the adoption of instructional strategies, individualized and customized learning directions, activity oriented learning, multiple assessments and attainments, student tracking strategies and techniques, and learning through adaptive tutoring systems. Additionally, it recommends combining a TPACK framework model with metacognition to help learners achieve their goals by navigating the talent, intelligent, and technological spaces while maintaining a high level of self-awareness.

Keywords: Metacognition, TPACK, M-TPACK, MCDM, TOPSIS, AHP

1. Introduction

a) Metacognition: It is essential to successful learning because it enables people to more effectively manage their cognitive abilities and identify areas that need cognitive ability development. Metacognition [2] includes the ability to evaluate how one applies a skill. Recent research indicates that learners who are aware of their own metacognition are more strategic and achieve higher levels of performance. Because of this awareness, people are better able to organize, plan, and keep track of their learning in ways that directly enhance their performance. The cognitive knowledge of students includes their knowledge of who they are, their coping mechanisms, and the circumstances in which they function best. Declarative, procedural, and conditional knowledge are the core elements of conceptual knowledge. The basis of cognitive regulation describes how a group of students creates and implements strategies, keeps track of their progress, corrects their reading errors, and inspects their learning. The higher-order executive processes that are in charge of directing and supervising cognition are included in Sternberg's framework along with the Meta components that determine what is required to be done, monitor ongoing activities, evaluate completed tasks, and collaborate with the performance and knowledge acquisition components that support learning. These elements together make up metacognition. Given its fundamental role in effective learning [3], it is imperative to explore the development and utilization of metacognition to enhance novice learners' proficiency in regulating their cognitive resources [4]. The two primary components of metacognition, according to Flavell's research, are knowledge of cognition and regulation of cognition. The term "metacognitive knowledge" refers to the reflective component of learning and includes knowledge that has the potential to affect both our awareness of and use of our cognitive processes. Schraw and Moshman further divide knowledge of metacognition into three subcomponents: Declarative Knowledge (DK), which represents our understanding of knowledge acquisition and its influence on learning; Procedural Knowledge (PK), which includes knowledge about effective memory and learning practices; and Conditional Knowledge (CK), which includes the knowledge of why and when to use particular strategies, facilitating resource allocation and enhancing strategy effectiveness. Contrarily, metacognitive regulations refer to specific actions that quicken the processes of learning and memorization. Three essential elements make up metacognitive regulation: planning, monitoring, and assessment. Monitoring entails assessing one's progress in learning or strategy utilization, while planning entails choosing the best cognitive resources and strategies for a given task. The critical evaluation of newly acquired knowledge is a component of assessment.

b) Benziger Thinking Style Assessment: The implications of BTSA [5] provide valuable insights into one's strengths and weaknesses, facilitating self-improvement and effective management of relationships and teams. Thinking style is evaluated based on four components: Basal Left , Basal Right, Frontal Left , and Frontal Right.

c) Kolb's Learning Style Preferences: Active experimentation (AE), abstract conceptualization (AC), reflective observation (RO), and concrete experience (CE) are the four types of learning capacities identified by Kolb's theory [6]. It makes the claim that learning preferences have an impact on a person's behavioral examination, learning and achievement specialization, career prospects, current position of employment, and dynamic competencies.

d) Multiple Intelligences: According to Howard Gardner, different degrees of distinct intelligence profiles exist in each person. The three types of multiple intelligences (MI) [8] are analytical (such as naturalistic, musical, and mathematical), introspective (such as linguistic, interpersonal, and bodily-kinesthetic), and interactive (such as intrapersonal and visuo-spatial).

e) Big Five Personality Traits: The Big Five Personality Theory describes five major dimensions of personality: openness, conscientiousness, extraversion, agreeableness, and neuroticism, often referred to as the Five-Factor Model (FFM) [7]. Each factor in the FFM [8] is further divided into two archetypes, totaling ten elements. These archetypes represent opposite ends of the spectrum, with characteristics such as Social, Calm, Organized, Accommodative, Inquisitiveness, Reserved, Limbic, Uncertainty, Unorganized, Ego-Centric, and Non-Curious.

2. Methodology

2.1 Data Set:

The survey included 1145 students who are enrolled in a university-level program for engineering. The psychometric theories [9] related attributes considered for this research are shown below:

MAI Components = { DK, PK,CK, PL ,IMS, CM, DS, EV, KAC, RAC}
Thinking Style= {BL, BR, FL, FL}
Learning Style= {AE, AC, RO, CE}
Multiple Intelligence= {Lin, Lo, Mu, Bo, Vi, Inter, Intra, Na}
Personality traits= {F1, F2, F3, F4, F5}

2.2 Decision making process:

Multiple Criteria Decision Making (MCDM) is a field of study that deals with making decisions in situations where multiple criteria or objectives need to be considered simultaneously. MCDM methods are used to analyze and prioritize alternatives based on these multiple criteria. The
MCDM Process follows a sequential approach as follows:

1) **Problem Identification:** Define the decision problem and identify the alternatives, criteria, and decision-makers involved.

2) **Selection of Criteria:** Pick the pertinent standards that will be applied to the evaluation of the alternatives. These standards ought to be quantifiable and reflect the goals of the selection process.
3) **Data Collection:** Gather data for each alternative with respect to the selected criteria.
4) Normalization: Normalize the data to bring all criteria to a common scale. This is important when criteria have different units or measurement scales.
5) **Weighting:** In order to reflect the relative importance of the criteria, give each one a weight. Depending on their preferences or using analytical techniques, those who make decisions may contribute these weights.
6) **Scoring:** Evaluate each alternative on each criterion to obtain a score or performance value.
7) Aggregation: Combine the scores for each alternative using a specific aggregation method. Common methods include weighted sum, weighted product, and fuzzy aggregation.
8) **Ranking and Selection:** Based on the total scores of the alternatives, order them. The best option is typically determined by the ranking of the alternatives.
9) **Sensitivity Analysis:** Assess the robustness of the results by varying criteria weights or making changes to the data to understand how sensitive the decision is to different inputs.
10) **Decision-Making:** Make a final decision based on the analysis and interpretation of the results.

2.3 Architecture:

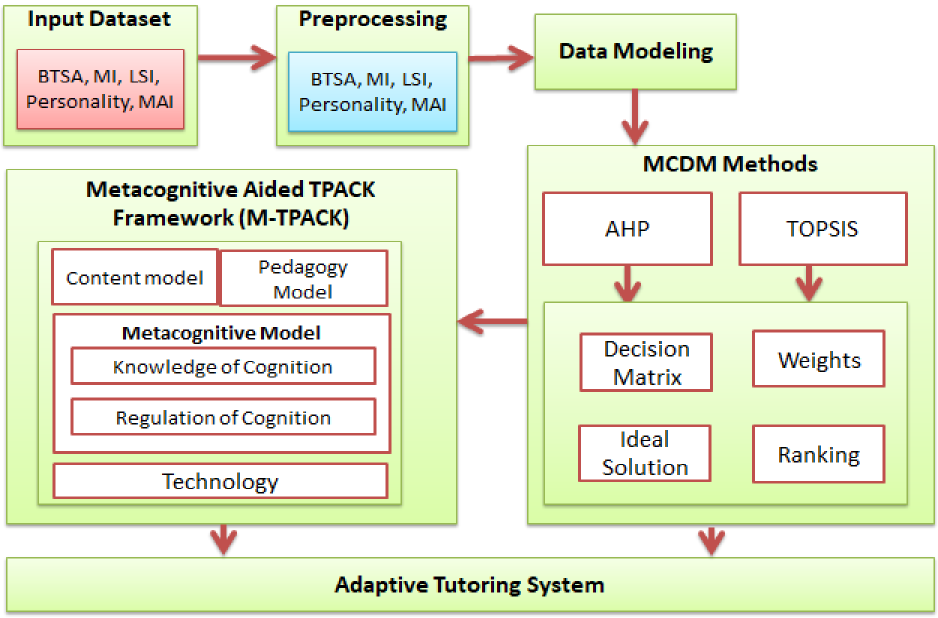

Fig 1: Architecture for Research Work

3. Multiple Criteria Decision Making Methods

3.1 Analytical Hierarchy Process (AHP)

Numerous competing and arbitrary criteria have been identified as being amenable to resolution using the Analytical Hierarchy Process (AHP) method [10]. The majority of the dataset consists of metacognitive mindfulness, personality traits, multiple intelligences, thinking style, style of learning scores. To determine the respondent profile with the best fit, the scores for thinking style and multiple intelligences should be higher while the scores for the BTSA factors need to be lower. It is a criterion that takes into accounts both min and max functions. AHP is a method for gathering and examining a wide range of parameters in circumstances requiring decision-making. Investigating the effects of different priority structures is crucial when rating students according to their cognitive and behavioral characteristics.

The consistency index is calculated as CI= (ƛ-n)/ (n-1)

Random index is calculated as RI= 1.98 *(n-2)/n

The consistency ratio is calculated as CI/RI.

If CR is below 0.10, accept the matrix. The consistency ratio value that was obtained is less than 10% (0.041354). This suggests that the subjective assessment is consistent. The alternative choice's overall composite weight is based on the weights assigned to levels 1 through 29. The Table displays each candidate's composite weight and ranking in ascending order. The Hierarchy Scores of AHP method is shown in Table-2 and Composite weights and rankings are shown in Table-3.

Table 2: The Hierarchy Scores of AHP method

Attributes	Priority	Rank	Attributes	Priority	Rank
Interpersonal	5.39	1	Frontal Right	4.66	3
Intrapersonal	5.09	2	Basal Right	4.09	5
Visio-spatial	4.24	4	Frontal Left	3.60	7
Bodily Kinesthetic	3.93	6	Basal Left	3.46	8
Linguistic	3.46	8	Concrete Experience	3.38	9
Logical-Mathematical	3.46	8	Reflective Observation	3.38	9
Natural	2.50	12	Abstract Conceptualization	3.38	9
Musical	2.40	13	Active Experimentation	3.38	9
F1	2.75	10	Planning	3.38	9
F2	2.60	11	Information Management Strategies	3.38	9
F3	2.60	11	Comprehension monitoring	3.38	9
F4	2.60	11	Debugging Strategies	3.38	9
F5	2.60	11	Evaluation	3.38	9
			Declarative Knowledge	3.38	9
			Procedural Knowledge	3.38	9
			Conditional Knowledge	3.38	9

Table 3: Composite weight and Ranking Order of AHP method

Student ID	Priority	Rank	Student ID	Priority	Rank
S472	0.6854463	1	…….	Lower rank	….
S569	0.6646793	2	S242	0.343064228	1140
S468	0.6643017	3	S416	0.308868935	1141
S432	0.664079	4	S1112	0.308182137	1142
S427	0.6489998	5	S590	0.295843077	1143
S185	0.6485635	6	S938	0.285417788	1144
S879	0.6473615	7	S764	0.279444462	1145

3.2 Technique for order performance by similarity to ideal solution (TOPSIS):

Prioritizing various attributes and criteria is made easier by it. a method for making decisions based on the idea that the best choice should be the one that is the furthest away from the worst case scenario and the

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closest to the best case scenario. In all, 1145 students' 29 attributes were used in this paper. The TOPSIS method's recommended step-by-step procedure is listed below. Table-4 displays the evaluated attribute hierarchical scores. The table-5 below contains an example of priority and student ranking data.The following is the methodology Using TOPSIS to solve the MCDM issue

Step1: The first step is to decide what the goal is and to pinpoint the relevant evaluation criteria.

Step2: Obtain th[illegible]cision matrix

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}}$$

Step3: Decide the relative weights of various attributes in relation to the objective, so that all of the summation of weights are equal to 1.

Step4: Get the weighted average Matrix normalized

$$V_{ij} = \overline{X}_{ij} \times W_j$$

Step5: Determine the ideal and negative (unfavourable) ideal solutions

Step6: Use the two equations below to calculate the separation measures.

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2\right]^{0.5} \quad S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2\right]^{0.5}$$ solution

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

Step8: Next, order the value of Pi in decreasing order based on the result

Table 6: Hierarchy Scores of TOPSIS methods

Student ID	Priority	Rank	Student ID	Priority	Rank
SID_162	0.5032	R1	…….	Lower rank	….
SID_36	0.5031	R2	SID_647	0.4553	R1140
SID_325	0.5012	R3	SID_1046	0.4549	R1141
SID_778	0.5007	R4	SID_188	0.4499	R1142
SID_655	0.5002	R5	SID_237	0.4495	R1143
SID_123	0.4993	R6	SID_133	0.4438	R1144
SID_163	0.4989	R7	SID_530	0.4387	R1145

Table 4: Composite weight and ranking of TOPSIS method

Attributes	Priority	Rank	Attributes	Priority	Rank
Logical-Mathematical	6.13%	2	Frontal Left	10.03%	1
Intrapersonal	4.33%	12	Frontal Right	1.58%	20
Interpersonal	4.22%	13	Basal Right	0.90%	22
Visio-spatial	3.13%	15	Basal Left	0.09%	29
Linguistic	2.41%	18	Procedural Knowledge	6.03%	3
Musical	0.67%	25	Declarative Knowledge	5.97%	4
Bodily Kinesthetic	0.53%	27	Planning	5.85%	5
Natural	0.44%	28	Conditional Knowledge	5.85%	6
F3	4.55%	11	Comprehension monitoring	5.83%	7
F2	1.19%	21	Information Management Strategies	5.83%	8

F5	0.84%	23	Evaluation	5.82%	9
F1	0.73%	24	Debugging Strategies	5.52%	10
F4	0.61%	26	Abstract Conceptualization	2.60%	17
Active Experimentation	3.45%	14	Concrete Experience	1.71%	19
Reflective Observation	3.09%	16			

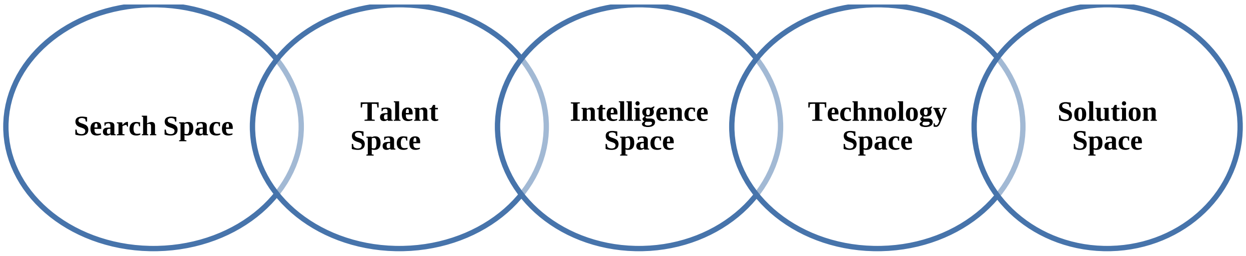

Fig 2: Goal Driven approach from Search space to Solution space

4. M-TPACK Framework

Search Space may be defined with set of learners with multiple dimensions at multiple levels in cognition. Talent Space includes the cognitive traits of learners which include learner's thinking style, learning style, multiple intelligence and their personality traits. Intelligence Space includes metacognition levels of learners, which reveals learners knowledge, planning, and debugging and evaluation skills to obtain a solution to given problem as shown in Figure-2. Technology Space plays a prominent role where a learner gains knowledge utilizing their talent space and intelligence space through enabled experiential learning. The solution space is the set of all possible solutions for the combinatorial optimization problem. Though every individual having cognitive levels at certain proportion, metacognition plays a crucial role from navigate between learn, unlearn and relearn in cyclic phenomenon. In this connection, Metacognition aided Technology, Pedagogy and Content knowledge Framework through adaptive tutoring system is proposed to the learners to reach their goal state in solution space driving through talent space, intelligent space and technology space. As shown in Figure-3 M-TPACK is an integral framework of Technological Pedagogical Content Knowledge aided with Metacognition(TPCM),Technological Pedagogical Knowledge(TPK), Technological Content Knowledge(TCK),Technological Content with Metacognition Knowledge(TCM), Metacognition based Content Knowledge(MCK),Content pedagogical Metacognitive Knowledge(CPM), Metacognitive Pedagogical Knowledge(MPK),Technological Pedagogical Metacognitive Knowledge(TPM), Technological Pedagogical Content Knowledge(TPC).

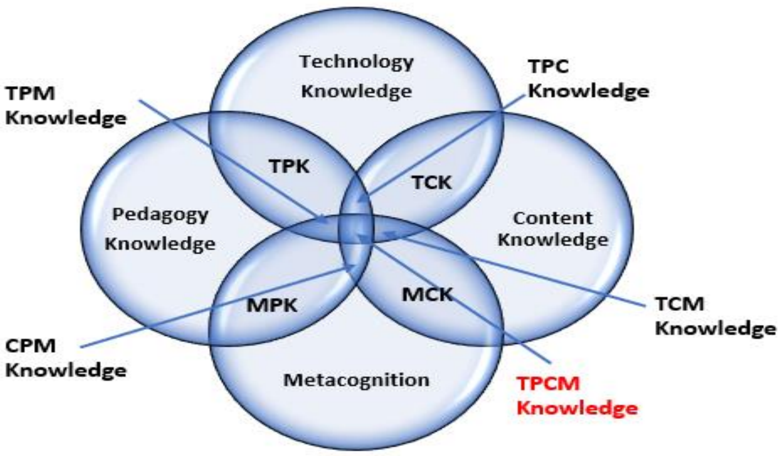

Fig 3: Metacognitive aided TPACK framework

5. Conclusion

Findings from the use of Multi Criteria Decision Making Methods likely AHP and TOPSIS aid educators, psychologists, counselors, and students in developing their computer programming skills. The MCDM outcome ranking order can be used to implement strategies for instruction, customized learning paths, learning activities, learning assessments, student monitoring methods, and learning through adaptive tutoring systems. Additionally, it suggests using the TPACK framework model with Metacognition to help learners achieve their goals by utilizing their skills in the talent, intelligence, and technology spaces while maintaining high levels of cognitive and metacognitive awareness. a future The goal of this research is to create a hybrid approach using the TOPSIS method and AHP. An adaptive tutoring system using metacognition is being proposed to help all students' programming skills.

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