Paper 1

A Brief Overview of Logical-Mathematical Intelligence

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Abstract
Gardner's Theory of Multiple Intelligences (TMI) provides a comprehensive framework for understanding human cognition by recognizing various distinct intelligences. This perspective underscores the complexity and diversity of cognitive abilities and offers valuable implications for education, personal development, and the appreciation of diverse talents. Among these intelligences, Logical-Mathematical Intelligence (LMIQ) stands out as a crucial cognitive skill that underpins systematic reasoning and quantitative analysis. LMIQ is essential in fields such as mathematics, science, engineering, and finance, illustrating its significance across both academic and practical domains. Understanding and fostering LMIQ in educational settings can enhance learning experiences and help individuals apply their strengths in various contexts. Additionally, the Cattell-Horn-Carroll (CHC) theory provides a useful framework for dissecting cognitive abilities related to mathematics and numeracy, aiding in the effective teaching and learning of these skills.
Keywords: CHC Theory, Cognitive Abilities, Logical-Mathematical Intelligence (LMIQ), Gardner's Theory of Multiple Intelligences (TMI)

A Quick Look at the Theory of Multiple Intelligences

Howard Gardner's Theory of Multiple Intelligences (TMI; cited in Helding, 2009) was first introduced to the world in his book "Frames of Mind: The Theory of Multiple Intelligences" (Gardner, 1983). His theory has proposed that we are not born with all the multiple intelligence(s) we shall ever have. Gardner's TMI has fundamentally transformed our current understanding of human intelligence. In his original treatise (Gardner, 1983) and subsequent one (Gardner, 2008), Gardner, who is an American developmental psychologist and the John H. and Elisabeth A. Hobbs Research Professor of Cognition and Education at Harvard University (cited in Gordon, 2006), argued that traditional measures of intelligence (e.g., traditional IQ tests) are too narrow and do not capture the full spectrum of human cognitive abilities (also see Almeida et al., 2010). Instead, he suggested that intelligence is not a single, unified entity but rather a collection of distinct, autonomous intelligences. This theory challenges the traditional view by proposing that individuals possess a variety of intelligences that reflect different ways of processing information and solving problems.

According to Howard's TMI, there are eight different intelligences (cited in Davis et al., 2011) and they are listed and breifly described as follows: First, the Linguistic Intelligence (LinIQ) that involves sensitivity to spoken and written language. It encompasses the ability to use language effectively for various purposes such as reading, writing, storytelling, and learning new languages. Individuals with high LinIQ are often skilled at expressing themselves verbally and are adept at manipulating language to achieve specific effects. The LinIQ is typically strong in poets, writers, journalists, and public speakers. It also plays a crucial role in academic success, especially in fields that require extensive reading and writing. Second, the Logical-Mathematical Intelligence (LMIQ) pertains to the ability to reason logically and solve mathematical problems. It involves skills such as abstract thinking, deductive reasoning, and problem-solving. Individuals with high LMIQ often excel in working with numbers, patterns, and scientific concepts. Mathematicians, scientists, engineers, and analysts often display strong LMIQ. This type of intelligence is heavily emphasized in traditional educational systems, particularly in mathematics and science curricula. Third, the Spatial Intelligence (SpIQ) refers to the capacity to think in three dimensions and to visualize spatial relationships. It involves skills related to navigation, spatial reasoning, and the ability to create and manipulate mental images. People with high spatial intelligence are often skilled at tasks that require visualizing and organizing space, such as in architecture, engineering, or art. Artists, architects, and pilots are examples of individuals who may possess strong SPIQ. Fourth, the Bodily-Kinesthetic Intelligence (BKIQ) is characterized by the ability to use one's body effectively for physical tasks. It includes skills such as coordination, dexterity, and the ability to perform actions with precision. Generally, BKIQ is crucial for activities involving physical movement and manipulation (e.g., dance nd movement, sports, and hands-on craftsmanship or apprenticeship). Athletes, dancers, surgeons, and craftspeople are typically strong in this intelligence. Fifth, the Musical Intelligence (MusIQ) involves sensitivity to rhythm, tone, pitch, and melody. It encompasses the ability to understand, create, and appreciate music. Individuals with high MusIQ are often able to discern musical patterns and structures and may have a strong sense of rhythm and pitch. Musicians, composers, singers, and music teachers are examples of those who demonstrate high MusIQ that supports the ability to engage with and create music in various forms. Sixth, the Interpersonal Intelligence (InterpIQ) is the capacity to understand and interact effectively with others. It includes skills such as empathy, communication, and the ability to discern social cues and dynamics. People with high interpersonal intelligence excel in managing relationships and navigating social contexts. This intelligence is vital for professions that require interaction with others, such as teaching, counseling, and leadership roles. Effective leaders, therapists, and educators often exhibit strong InterpIQ. Seventh, the Intrapersonal Intelligence (intrapIQ) refers to the ability to understand oneself, including one's own emotions, motivations, and goals. It involves self-reflection, self-awareness, and personal insight. individuals with high IntrapIQ are adept at self-regulation and personal growth. They are often introspective and capable of setting and pursuing personal objectives. Philosophers, psychologists, and individuals engaged in self-improvement activities may exhibit high IntrapIQ. Eighth and lastly, the Naturalistic Intelligence (NaIQ) involves the ability to recognize, categorize, and draw upon features of the natural environment. It includes skills related to observing and understanding the natural world, such as distinguishing between different types of plants and animals or understanding ecological systems. Individuals with high naturalistic intelligence are often engaged in activities related to the environment, such as biology, agriculture, or environmental conservation. Biologists, environmentalists, and farmers typically demonstrate strong NaIQ.

Implications of Gardner's Theory of Multiple Intelligences

Liu and Xie (2024) have identified Gardner's TMI as "one of the best known non-CHC[1] models (see Schneider & McGrew, 2012, for detail) … under the Quotient code, which is known as Q-code for short … in his book 'Frames of Mind: The Theory of Mulitple Intelligences' (Gardner, 1983)" (p. 32). The authors have also added further that the TMI "suggests that an intelligence 'modality' needs to meet eight conditions: (1) it should be isolatable by brain damage, (2) have a place in evolutionary history, (3) include core operations, (4) be symbolically expressible, (5) exhibit a distinct developmental progression, (6) involve individuals with exceptional abilities, (7) be supported by experimental psychology, and (8) be backed by psychometric evidence (see Gilman, 2001, for detail)" (p. 32).

According to Elena and Suzana (2016), Gardner's TMI has had significant implications for education and beyond. In educational settings, the TMI model promotes a more personalized approach to teaching, recognizing that students learn in diverse ways and have different strengths. Educators are encouraged to use varied instructional methods to cater to multiple intelligences, thus supporting a broader range of learning styles and enhancing overall student engagement.

In addition, the TMI also underscores the importance of valuing and developing all types of intelligence, rather than focusing solely on traditional academic skills. By acknowledging the diverse ways in which people process information and solve problems, Gardner's (1983) theory provides a more inclusive framework for understanding human capabilities and potential.

Logical-Mathematical Intelligence: The Narrow Cognitive Abilities

In this paper, the author has chosen to target his focus on Logical-Mathematical Intelligence (LMIQ), which he has regarded as a broad cognitive ability in the non-CHC model (Liu & Xie, 2024) of the TMI (Gardner, 1983, 2008). This form of broad cognitive ability or intelligence encompasses the ability to reason logically, think critically, and solve mathematical problems. Moreover, it involves skills such as abstract thinking, pattern recognition, and systematic problem-solving (Shirawia et al., 223). Individuals with strong LMIQ often excel in areas that require

[1] CHC model stands for Cattell-Horn-Carroll model of cognitive abilities (Schneider & McGrew, 2012).

analytical reasoning and quantitative analysis. This intelligence is central to fields such as mathematics, science, engineering, and computer programming, but its applications extend far beyond these disciplines.

The author has identified several key narrow cognitive abilities of LMIQ (see Figure 1) and argues that educators as well as educational therapists working with students with mathematics learning difficulties have to take note to ensure best practice in the field of mathematics pedagogy. The first narrow cognitive ability in LMIQ is the Abstract Reasoning (AR) and it involves the ability to think abstractly and understand complex concepts that are not necessarily tangible. This means being able to work with ideas and symbols rather than concrete objects. For instance, an individual with strong LMIQ can understand and manipulate variables in algebra or conceptualize theoretical scenarios in physics. Next, the Pattern Recognition (PR) is another fundamental aspect of LMIQ that involves recognizing patterns and structures. This narrow cognitive ability allows individuals to identify regularities and anomalies within data or sequences. For example, a mathematician might spot a pattern in a series of numbers, while a computer scientist might recognize patterns in code that help in debugging. The third narrow cognitive ability in LMIQ is the Systematic Problem-Solving (SPS). Generally, individuals with high LMIQ are adept at approaching problems systematically. They often break down complex problems into smaller, manageable parts, analyze these components, and then synthesize solutions based on their analysis. This methodical approach is crucial in fields that require detailed and precise work, such as engineering or statistical analysis. Quantitative Analysis (QA), another narrow cognitive ability, are concerned with quantitative skills that constitute the hallmark of LMIQ. Individuals with this QA ability are proficient in handling numbers, performing calculations, and analyzing numerical data. This also includes understanding statistical measures, probabilities, and mathematical relationships that are integral to fields like economics and finance. Critical Thinking (CT) in LMIQ also contributes a crucial role as a narrow cognitive ability, involving the ability to evaluate arguments and evidence critically. Individuals with this quantitative ability are skilled at assessing the validity of different propositions, drawing logical conclusions, and avoiding cognitive biases. Critical thinking is essential in academic research, scientific experimentation, and strategic decision-making.

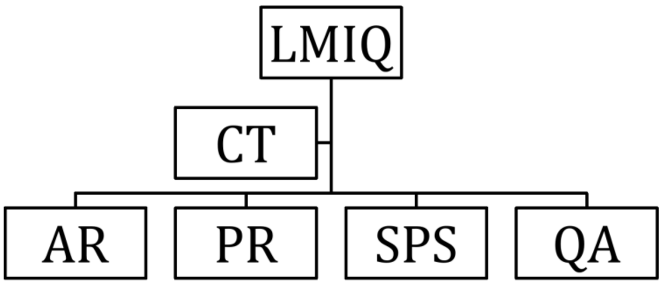

Figure 1. The Narrow Cognitive Abilities of LMIQ

Practical Applications of Logical-Mathematical Intelligence

Logical-mathematical intelligence (LMIQ) is crucial in various domains, each leveraging its distinct characteristics in different ways (Niroo, Nejhad, & Haghani, 2012). In the academic subject (field) of mathematics, LMIQ is essential for solving problems, proving theories, and understanding abstract concepts. Students of mathematics as well as mathematicians themselves rely on the use this intelligence to explore new mathematical realms, develop algorithms, and apply mathematical principles to real-world situations.

In addition, the scientific method relies heavily on LMIQ too. For instance, research scientists use logical reasoning to form hypotheses, design experiments, and interpret data. Whether in physics, chemistry, or biology, scientific inquiry depends on the ability to apply mathematical concepts and analyze results systematically.

Besides, the wide field of engineering requires LMIQ to design, analyze, and optimize systems and structures. Engineers use mathematical models to simulate real-world conditions, solve design challenges, and ensure the functionality and safety of various technologies.

Today, in computer science, LMIQ has become even more vital for programming, algorithm development, and data analysis. Computer scientists and software developers use this intelligence to write code, create software solutions, and address complex computational problems. Not forgetting, too, that in the fields of finance and economics, LMIQ plays a significant role in finance and economics. Professionals in these fields analyze market trends, model financial scenarios, and make data-driven decisions. Skills in quantitative analysis and statistical reasoning are crucial for evaluating economic conditions and investment opportunities.

Educational Implications of TMI Application

According to Gardner and Hatch (1989), understanding LMIQ has important implications for regular/mainstream education as well as educational therapy (intervention for students with mathematics learning challenges). Recognizing that students have varying strengths in different types of intelligence allows educators to tailor their teaching methods to better support diverse learning styles (Mokhtar, Majid, & Foo, 2008). For students with strong LMIQ, engaging with challenging problems, exploring mathematical concepts, and participating in activities that require critical thinking can enhance their learning experience (Elena & Suzana, 2016).

In terms of differentiated instruction in mathematics pedagogy, teachers can use the approach to cater to students with strong LMIQ by creating opportunities for advanced problem-solving, exploratory activities in mathematics and science, and projects that involve analytical reasoning. For those with lower or weak LMIQ, worksheets can be simplified to cater to those students who are slow learners. Task analysis can also be an appropriate approach to teaching and/or learning mathematics. It is a systematic process used to break down complex tasks into smaller, more manageable components. Examples of task analysis include activities such as breaking down mathematical problems, creating sequential learning objectives, identifying prerequisite skills, designing effective instructional strategies, assessing and monitoring progress, and differentiating instruction. Therefore, the approach helps in understanding the specific steps or skills required to complete a task successfully. Hence, in education, task analysis is particularly useful for teaching as well as in educational therapy because it allows educators and/or educational therapists to deconstruct tasks into individual learning objectives and identify the prerequisites needed for mastering each step. By employing task analysis, both educators and educational therapists can provide more structured and effective instruction, ensuring that students build a solid foundation in basic mathematical concepts. It allows for a clear, step-by-step approach that can be adapted to meet the diverse needs of learners.

There are also many strategies relevant to mathematics education. One example is the Hands-On Learning. This strategy incorporates hands-on activities that require logical and mathematical reasoning can help students with this intelligence engage more deeply with the material. This might include experiments, puzzles, or real-world applications of mathematical concepts. Another example is to encourage students to tap on analytical thinking. Classroom teachers can always foster LMIQ by encouraging their students to think critically about problems, analyze data, and draw reasoned conclusions. By providing opportunities for debate and discussion on complex topics, teachers can help to enhance critical thinking skills in students. A third example is to support and promote diverse learning styles in mathematics. While LMIQ is crucial for some subjects, a balanced approach to education recognizes that other forms of intelligence are equally valuable. Incorporating a range of teaching strategies ensures that all students have the opportunity to develop their unique strengths. Table 1 provides a brief description of LMIQ.

Table 1. A Brief Description of LMIQ

Aspect	Description
Definition	The ability to reason logically, think abstractly, and solve mathematical problems.
Key Characteristics	- Abstract reasoning - Pattern recognition - Systematic problem-solving - Quantitative skills - Critical thinking
Skills Involved	- Handling abstract concepts and symbols - Identifying and analyzing patterns - Performing calculations - Evaluating arguments and evidence
Typical Professions	- Mathematician - Scientist - Engineer

Aspect	Description
	- Computer Programmer - Financial Analyst
Educational Implications	- Tailoring instruction to advanced problem-solving - Engaging in hands-on, practical activities - Encouraging analytical thinking
Applications	- Mathematics - Science - Engineering - Computer Science - Finance and Economics

Table 1 above provides a concise summary of LMIQ, highlighting its definition, key characteristics, skills, typical professions, educational implications, and applications.

Activities of Engagement in Effective Mathematics Learning

Learning processes that cater to LMIQ focus on enhancing abstract reasoning, pattern recognition, problem-solving, and quantitative skills. The author has provided a general guide to promote optimization of mathematics learning for individuals with strong LMIQ (see Table 2 below).

Table 2. Activities of Engagement in Mathematics Learning

Learning Process	Description	Techniques
1. Engage with Complex Problems	Present learners with challenging problems that require deep analysis and logical reasoning.	• **Puzzles and Riddles**: Use logic puzzles, Sudoku, or brain teasers to stimulate problem-solving skills. • **Real-World Scenarios**: Incorporate case studies or complex scenarios related to mathematics, science, or engineering.
2. Promote Systematic Problem-Solving	Encourage a methodical approach to breaking down and solving problems.	• **Step-by-Step Procedures**: Teach learners to decompose problems into smaller, manageable parts and tackle them systematically. • **Flowcharts and Diagrams**: Use visual aids to map out problem-solving processes and logical sequences.
3. Utilize Hands-On Activities	Apply mathematical and logical concepts through interactive and practical exercises.	• **Experiments**: Conduct scientific experiments that require data collection and analysis. • **Simulations**: Use software tools or simulations to model mathematical problems or engineering designs.
4. Foster Abstract Thinking	Develop the ability to think about concepts that are not immediately tangible or visible.	• **Theoretical Exercises**: Engage in exercises that involve abstract concepts, such as algebraic equations or geometric proofs.

		• **Concept Mapping**: Create mind maps or concept diagrams to visualize relationships between abstract ideas.
5. Encourage Pattern Recognition	Enhance the ability to identify and analyze patterns and structures.	• **Pattern-Based Activities**: Work with sequences, series, and algebraic patterns. • **Data Analysis**: Analyze datasets to find trends, correlations, and patterns.
6. Integrate Quantitative Analysis	Develop skills in handling numerical data and performing calculations.	• **Mathematical Modeling**: Create and analyze mathematical models to represent real-world phenomena. • **Statistical Analysis**: Use statistical methods to interpret data and make informed decisions.
7. Cultivate Critical Thinking	Enhance the ability to evaluate arguments, evidence, and conclusions critically.	• **Debates and Discussions**: Engage in debates on logical or mathematical topics to practice evaluating different viewpoints or perspectives. • **Critical Review**: Analyze and critique research papers, mathematical proofs, or scientific studies.
8. Provide Opportunities for Exploration	Allow learners to explore topics of interest in depth and apply their knowledge creatively.	• **Independent Projects**: Encourage learners to undertake projects that involve solving complex problems or creating innovative solutions. • **Advanced Courses**: Offer opportunities to study advanced topics in mathematics, science, or technology.
9. Encourage Collaborative Learning	Facilitate collaboration with others to enhance problem-solving and analytical skills.	• **Group Projects**: Work on group projects that require collective problem-solving and analytical thinking. • **Peer Teaching**: Encourage learners to explain concepts to peers, reinforcing their understanding through teaching.
10. Use Technology and Tools	Leverage technology to enhance learning and problem-solving capabilities.	• **Mathematical Software**: Utilize software for algebra, calculus, or statistical analysis (e.g., MATLAB, Mathematica).

	• **Programming Tools**: Introduce programming languages and tools for computational problem-solving (e.g., Python, R).

The Importance of LMIQ

Logical-Mathematical Intelligence (LMIQ) is important for several reasons, both in personal development and in various professional fields. The author of this paper reiterates his reasons as follows: First and foremost, LMIQ sets the foundation for academic success. For instance, in mathematics as well as science, LMIQ is essential for understanding and excelling in mathematics and science. These subjects often require the ability to grasp abstract concepts, solve complex problems, and apply quantitative reasoning. Another example is critical thinking.

LMIQ fosters critical thinking skills, which are important for academic achievement across disciplines. This includes the ability to evaluate arguments, analyze evidence, and construct reasoned conclusions. Next, LMIQ is certainly essential for problem-solving skills. In complex challenges, for example, LMIQ equips individuals with the skills to tackle complex problems by breaking them down into manageable parts and applying logical processes. This approach is valuable in fields that require detailed problem analysis and innovative solutions. Also, in real-world applications, from troubleshooting technical issues to developing strategies for business challenges, strong problem-solving skills can lead to effective solutions and improved outcomes.

Third, LMIQ is crucial for professional development. Especially in engineering, computer science, and technology sectors, LMIQ is vital for designing systems, coding software, and optimizing processes. Professionals use mathematical models and logical reasoning to innovate and solve technical problems. As already mentioned earlier, in finance, economics, and data analysis, LMIQ helps with financial forecasting, market analysis, and risk assessment. Quantitative skills are crucial for making informed financial decisions and developing economic strategies.

Fourth, decision-making abilities often rely on LMIQ, such as in data-driven decisions, where LMIQ supports the ability to make data-driven decisions by analyzing numerical data and identifying trends. This is important in fields like business analytics, research, and policy-making. In addition, in strategic planning, LMIQ aids in strategic planning by enabling individuals to forecast potential outcomes, assess risks, and develop strategies based on logical analysis and quantitative evidence.

In the arena of innovation and creativity, research and development requires LMIQ to contribute to innovation by allowing individuals to explore new ideas, develop theoretical models, and test hypotheses. It drives progress in scientific discoveries and technological advancements. Moreover, in creative problem-solving, while it may seem counterintuitive, LMQ also fosters creative problem-solving. By understanding and manipulating abstract concepts, individuals can devise novel solutions and approaches to various challenges.

Next, LMIQ helps in the enhancement of an individual's cognitive skills. For example, in abstract thinking, LMIQ helps develop the ability to think abstractly, which is beneficial for understanding complex concepts and making connections between seemingly unrelated ideas. In another example, in analytical reasoning, LMIQ enhances analytical reasoning skills, which are crucial for evaluating information critically and making reasoned judgments in both professional and personal contexts.

In terms of educational and career opportunities, many specialized careers may require strong LMIQ, including roles in engineering, computer science, finance, and scientific research. Mastery of LMQ can open doors to specialized and high-demand professions. Also, success in fields such as mathematics, engineering, and science often relies on a high level of LMIQ, which is linked to academic achievements and advanced degrees in these areas.

Finally, in the contribution of LMIQ to technological and scientific advancements, this intelligence drives technological innovation by enabling professionals to develop new technologies, improve existing systems, and solve technical problems with precision. Also, in scientific research, LMIQ is crucial for designing experiments, analyzing results, and developing theories that advance knowledge in various scientific fields.

LMIQ within the Context of Cattell-Horn-Carroll Theory of Cognitive Abilities

In the context of educational psychology (especially in diagnostic assessment) and educational therapy (espeically in differentiated intervention), the Cattell-Horn-Carroll (CHC) theory provides a comprehensive framework for understanding human cognitive abilities and the applications in treatment of those with learning and behavioral challenges. In the area of mathematics and numeracy, this CHC theory helps to identify the broad and narrow abilities that contribute to mathematical skills. Table 3A (broad abilities) as well as Table 3b (narrow abilities) provides a simplified CHC-based approach that helps to conceptualize a cognition-based competence framework that encompasses both broad and narrow abilities (CHC G-codes) for mathematical performance based on the CHC theory as well as other narrow abilities (not found in the CHC table of cognitive abilities) based on the Q-codes of the non-CHC approach (e.g., TMI) as follows:

Table 3A. The CHC-Based Framework of Broad Cognitive Abilities in LMIQ

Broad Cognitive Abilities	**CHC G-Codes**	**Description**
Fluid Intelligence	Gf	This involves the ability to reason and solve novel problems, which is crucial for tackling complex mathematical problems and understanding abstract concepts.
Crystallized Intelligence	Gc	This includes knowledge and skills acquired through education and experience, such as mathematical knowledge, vocabulary, and factual knowledge.
Quantitative Knowledge	Gq	This is directly related to mathematical reasoning and problem-solving. It involves understanding numerical relationships, mathematical concepts, and solving numerical problems.
Working Memory	Gwm	This is the ability to hold and manipulate information over short periods. It is essential for performing multi-step calculations and keeping track of intermediate results in mathematical problems.
Processing Speed	Gs	This refers to the speed at which one can process information. Faster processing speeds can contribute to more efficient problem-solving in mathematics.
Visual Processing	Gv	This includes the ability to visualize and manipulate objects mentally, which can be important for geometry and spatial reasoning tasks in mathematics.

Table 3B. The CHC-Based Framework of Narrow Cognitive Abilities in LMIQ

Narrow Cognitive Abilities	**CHC G-Codes / non-CHC Q-codes**	**Description**
Number Facility	Gs-N	This involves the ability to perform basic arithmetic operations quickly and accurately.
Mathematical Problem-Solving	LMIQ-MPS	This is the ability to solve complex mathematical problems that require the integration of various mathematical concepts and strategies.
Quantitative Reasoning / Mathematical Reasoning	Gf-RQ LMIQ-MR	The ability to apply logical reasoning to solve mathematical problems and understand abstract mathematical concepts.
Visualization	Gv-Vz	While not exclusively mathematical, spatial visualization involves the ability to understand and manipulate shapes and objects in space, which can be important for geometry and spatial reasoning in mathematics.
Spatial Scanning	Gv-SS	
Memory for Numbers	MathQ-Mn	The ability to recall numerical information and perform mental calculations. These abilities interact and contribute to an individual’s overall mathematical and numeracy

		skills. Effective teaching and assessment can benefit from considering these different dimensions to better support learners' development in mathematics

Though the CHC theory of broad and narrow abilities for LMIQ remains a prominent model in cognitive psychology that categorizes cognitive abilities into various broad and narrow factors, it is still incomplete as it does not address many other narrow abilities found in the non-CHC model for Mathematical Intelligence or Mathematics Quotient (MathQ) (Lazaro-Quilang, 2021). When addressing mathematical performance using CHC theory, it is still crucial to know and comprehend the specific cognitive abilities that influence this MathQ or LMIQ.

A Cognitive Equation for Mathematical Performance

Mathematics performance (MP) refers to an individual's ability to accurately and effectively solve mathematical problems, demonstrating both procedural skills and conceptual understanding. It includes problem-solving aptitude, application of mathematical concepts, and the ability to reason and justify solutions (see Lane et al., 1996). Putting all the related CHC-based G-code broad and narrow abilities into a cognitive equation for MP, the term 'mathematical performance' (MP) can be presented as a function (f) in the proposed equation of these LMIQ-related cognitive abilities as follows by the author:

$$MP = f(Gf, Gc, Gq, Gwm, Gs, Gv)$$

Where the following abbreviations are briefly described:

- Gf (Fluid Intelligence) contributes to novel problem-solving and understanding abstract mathematical concepts.
- Gc (Crystallized Intelligence) provides the knowledge and learned skills applied to mathematical problems.
- Gq (Quantitative Reasoning) directly affects one's ability to perform and solve mathematical tasks.
- Gwm (Working Memory) supports holding and processing intermediate steps during mathematical problem-solving.
- Gs (Processing Speed) influences how quickly and efficiently mathematical operations are performed.
- Gv (Visual-Spatial Processing) affects the ability to understand and work with spatial representations and geometric problems.

A Cognitive Equation for Mathematics & Numeracy Learning

Similarly, a cognitive equation created for mathematics and numeracy learning (MNL) also involves integrating various cognitive abilities (both broad and narrow) that contribute to mathematical learning process. While such an equation would be a simplified representation, it can provide a better understanding of the interplay of different cognitive skills. Based on established theories of intelligence and learning (e.g., Da Fonseca et al., 2004; Sterberg, 2018), the following six key CHC-based cognitive factors for mathematics and numeracy learning are involved: Gf (fluid intelligence, which is crucial for learning and applying new mathematical concepts; Gc (crystallized intelligence), i.e., knowledge and skills acquired through experience, including mathematical facts and procedures; Gq (quantitative knowledge), which refers to the ability to understand and use numerical and mathematical concepts effectively; Gwm (working memory), which concerns the ability to hold and manipulate information in the short term, essential for performing calculations and solving complex problems; Gs (processing speed), which affects how swiftly one can complete MP-related tasks; and Gv (visual processing), which is the ability to visualize and manipulate objects, relevant for understanding geometric and spatial aspects of mathematics; and one non-CHC-based cognitive factor MathQ-SE (mathematical self-efficacy) that concerns the beliefs in one's ability to perform and succeed in mathematical tasks, which can affect motivation and persistence.

Like MP, the cognitive equation for MNL can be represented as a function (f) of these CHC-based cognitive factors as put forth by the author:

$$ML = f(Gf, Gc, Gq, Gwm, Gs, Gv, SE)$$

Where the following abbreviations are briefly described:

- Gf (Fluid Intelligence) impacts the ability to understand and apply new mathematical concepts.

- Gc (Crystallized Intelligence) provides the necessary background knowledge and skills.
- Gq (Quantitative Reasoning) directly affects the ability to solve mathematical problems.
- Gwm (Working Memory) supports the handling of multiple steps and information during problem-solving.
- Gs (Processing Speed) affects the efficiency of performing mathematical operations.
- Gv (Visual-Spatial Processing) influences the understanding of spatial and geometric aspects of math.
- SE (Mathematical Self-Efficacy) affects motivation, effort, and persistence in learning mathematics.

The application of the cognitive equation for MNL includes the following: (1) Assessment and diagnosis: Use the cognitive equation to assess a student's mathematical abilities and identify areas needing support; (2) Instructional planning: Tailor instructional strategies to strengthen weaker cognitive areas impacting math learning; and (3) Interventions: Develop targeted interventions to address specific cognitive deficits that may be hindering math learning. This cognitive equation for MNL provides a structured way to think about the various cognitive elements involved in the process of MNL to guide educational therapists in both assessment and instructional practices.

In the context of LMIQ, key terms in the cognitive equation for MNL can be understood as follows. LMIQ, as defined by Gardner's (1983, 2008) TMI, involves the ability to think logically, reason deductively, and handle complex numerical operations including: (1) Gf (fluid intelligence) that refers to the capacity to reason and solve novel problems without relying on previously acquired knowledge. In the context of logical-mathematical intelligence, it involves the ability to understand new mathematical concepts, solve unfamiliar problems, and think abstractly. Its relevance to LMIQ concerns how high Gf can help in tackling complex and unfamiliar mathematical problems and understanding abstract mathematical concepts; (2) Gc (crystallized intelligence) involves the knowledge and skills acquired through education and experience. In LMIQ, this includes learned mathematical facts, procedures, and problem-solving strategies. Its relevance to LMIQ concerns how a strong base in Gc can provide the necessary knowledge and skills to apply mathematical concepts effectively and solve routine problems; (3) Gq (quantitative reasoning) refers to the ability to understand and use numerical information and mathematical concepts to solve problems. It includes skills like numerical calculation, interpreting data, and making logical deductions based on quantitative information. Its relevance focuses on its essential application in performing calculations, interpreting data, and applying mathematical concepts to solve problems; (4) Gwm (working memory), already explained earlier in this paper, is the ability to hold and manipulate information over short periods. For mathematical problem-solving, it involves keeping track of intermediate steps, holding multiple numbers in mind, and managing multi-step calculations. Its relevance to LMIQ is that Gwm is critical for performing complex calculations and solving multi-step problems effectively; (5) Gs (processing speed) is the rate at which one can process information and perform cognitive tasks. In mathematics, it affects how quickly and efficiently one can execute calculations and solve problems. Its relevance to LIMQ is that the faster processing speed can lead to more efficient problem-solving and the ability to complete mathematical tasks more quickly; (6) Gv (visual processing) involves the ability to understand and manipulate spatial and geometric information. This includes visualizing geometric shapes, understanding spatial relationships, and solving problems involving diagrams or graphs. Its relevance to LIMQ is that it is important for tasks involving geometry, spatial reasoning, and interpreting graphical representations of data; and (7) MathQ-SE (mathematical self-efficacy) refers to an individual's belief in their ability to succeed in mathematical tasks. This belief can influence motivation, effort, and persistence in solving mathematical problems. Its relevance to LIMQ is that its higher self-efficacy can lead to increased motivation, greater effort, and improved performance in mathematics.

Conclusion

Gardner's TMI offers a comprehensive and nuanced perspective on intelligence. By identifying a range of distinct intelligences, Gardner (1983, 2008) has highlighted the complexity of human cognition and the variety of ways individuals interact with and understand the world around them. This approach not only broadens our current knowledge and understanding of intelligence but also has practical implications for education (including educational therapy), personal development, and appreciation of diverse talents.

Moreover, LMIQ is a multifaceted and vital form of cognitive ability that underpins much of one's understanding of the world through systematic reasoning and quantitative analysis. It manifests in various fields, from mathematics and science to engineering and finance, reflecting its importance in both academic and practical contexts. Recognizing and nurturing this intelligence in educational settings can enhance learning experiences and help individuals leverage their strengths in diverse domains. By appreciating the diverse ways in which people engage with and solve problems, we gain a richer understanding of human potential and cognitive diversity.

In the context of educational therapy, the CHC (Cattell-Horn-Carroll) theory provides a framework for understanding human cognitive abilities. For mathematics and numeracy learning (MNL), the theory helps to identify the broad and narrow cognitive abilities that contribute to the teaching and learning of mathematical skills.

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