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Mathematics capability: a MIMIC model based on the capability approach

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Abstract
The purpose of this study is to analyze students' mathematical abilities from a multifaceted capability approach viewpoint using data from PISA 2022 and to determine the variables influencing mathematics capabilities. This study attempts to define the mathematics capability variable by taking a cross-section from the PISA 2022 Turkey dataset and to identify possible student, household and school-related variables that explain this defined mathematics capability variable. The MIMIC model was employed to properly assess the study's dual objectives of defining a mathematics capability variable and determining potential variables that could account for this definition. This study has shown that students' mathematics capability depends on a variety of multifaceted elements, including self-efficacy, anxiety, teacher support, and the learning environment, in addition to academic achievement. Study habits, mathematical self-efficacy, and familiarity with mathematical ideas are the factors that most significantly predict mathematical ability. These results highlight the need for equality initiatives in education to be grounded on both opportunities and a practical conception of equality that takes into account the circumstances of each individual. Amartya Sen's Capability Approach and examined using the MIMIC model, test results by themselves are not enough to gauge mathematics capability; cognitive and affective elements must be considered.

Keywords Mathematics capability · Capability approach · MIMIC · Structural equation modeling

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1 Introduction

OECD's PISA reports emphasize that mathematical literacy is crucial for success in education, work, and daily life. Students proficient in mathematics are more successful academically and are more likely to enter high-income professions. Mathematical competence also plays a key role in labor market competitiveness and is essential for progress in STEM (Science, Technology, Engineering, and Mathematics) fields (OECD 2019). From an economic perspective, individuals with strong math skills contribute to a more innovative and productive workforce. Conversely, limited math proficiency may hinder individuals from acquiring necessary financial, scientific, and technological skills, thereby exacerbating social inequalities (OECD 2018, 2019, 2021).

The concept of equality is generally considered as equality of opportunity. Equality of Educational Opportunity (1966), known as the Coleman Report, is considered one of the most comprehensive studies on equality in education. In his study of educational opportunity in U.S. schools, Coleman determined that the socio-economic status of families and the peer environment were the most significant factors influencing student achievement, and that differences in student performance were largely due to these socio-economic disparities. He expanded this concept by suggesting that equality of opportunity cannot be ensured simply by giving individuals the same resources, emphasizing the critical role of social capital (e.g., family support, peer influence) (Coleman 1988). Gamoran and Long (2006) evaluated the effects of the Coleman Report 40 years later and examined the developments in educational equality. They underscoreed that factors such as family economic status, home environment, school resource utilization, and teaching quality continue to play a determining role in achievement gaps. Thus, assuming that differences in student achievement can be equalized independently of contextual factors such as socioeconomic status, regional disparities, or teaching quality means ignoring existing educational injustices. Social inequality is profoundly driven by educational disadvantages, which encompass both restricted access to high-quality schooling and a dearth of supportive learning environments at home and in institutional settings (Dorling 2015; Piketty, 2014). According to the 2015 PISA report, academic achievement across participating nations is closely linked to students' socio-economic backgrounds and various school-level mediating factors (OECD, 2016). The report emphasizes that socio-economic status remains a decisive factor in determining a student's ability to capitalize on educational opportunities and skill development (OECD, 2016).

Amartya Sen's Capability Approach (CA), developed in the mid-1980s and 1990s, similarly argues that individuals have different characteristics and life contexts that must be considered in efforts to ensure educational equality. This approach links individual life stories with social arrangements and takes into account multiple dimensions of human well-being (Sen 1985, 1999). Rather than focusing solely on providing equal resources, it emphasizes producing fair outcomes by accounting for the conditions in which individuals live (Walker and Unterhalter 2007). According to Sen (1993), a person's capability depends on various factors such as personal characteristics and social arrangements. The social context and relationships can either enhance or restrict an individual's capabilities, with personal and interpersonal differences creating unique conditions for each person. Sen's (1992, 1999) conception of equity includes both subjective assessments and the recognition of human diversity as well as the role of social systems. CA thus considers not only the resources people have but also their freedom to achieve the functionings they value. Kelly (2012)

and Walker (2005) also emphasize the value of the Capability Approach in broadening how educational outcomes are conceptualized.

A second core idea in the capability approach is the distinction between capabilities and functionings (Sen 1980). Functionings are achieved out-comes. Reading, talking to children, taking part in the social life of a community through attending a meeting about a school, being calm, are all functionings. Capabilities are the potential to achieve these functionings, for example, having been taught to read; having books or newspapers available to read; living in a society where adults of your class, gender, or race are permitted to talk to children and attend meetings at a school; and having the conditions that will develop calm (not too long a working day or too many anxieties). The difference between a capability and function-ing is one between an opportunity to achieve and the actual achievement, between potential and outcome (Walker and Unterhalter 2007).

One major challenge in applying the Capability Approach is that an individual's range of possible outcomes — their "capability set" — is not directly observable. An individual's capability set is unobservable (latent); researchers can only observe the achieved functionings (outcomes) and the conversion factors (exogenous causes) that influence them. So, we can observe the functionings (i.e., outcomes) that people achieve, but we cannot directly observe the range of opportunities from which they chose. Most empirical applications of CA use a set of multiple outcome indicators, combining them using specific criteria to approximate the idea of a capability set (Krishnakumar and Chavez-Juarez, 2016).

While traditional approaches (e.g., standard regression) only measure directly observable outcomes (functionings), the Multiple Indicators Multiple Causes (MIMIC) model—a specific form of Structural equation models (SEM)—enables the estimation of this unobservable 'capability' as a latent variable (Krishnakumar and Chavez-Juarez, 2016). Theoretically, the MIMIC model integrates two distinct mechanisms into a single framework. The measurement equation links the unobservable capability to its observable indicators (functionings, such as math test scores and class participation). Simultaneously, the structural equation determines how exogenous economic, social, and individual factors shape this latent capability. While traditional models predominantly measure the extent of achieved outcomes (success), the MIMIC model incorporates external factors into the theoretical framework. Consequently, it elucidates not only 'what has been achieved' but also 'how these capabilities can be enhanced' by identifying specific levers for intervention, such as policy adjustments or resource allocation (De Rosa 2018).

SEM is used extensively in psychometrics and sociology, it is also increasingly used in the context of capability operationalization (Addabbo et al. 2016; Di Tommaso 2007; Kuklys 2005; Krishnakumar 2007; Krishnakumar and Ballon 2008; Krishnakumar and Chavez-Juarez, 2016; Sarr and Ba 2017; Tsai et al. 2017; Wagle 2009). Krishnakumar (2007) stresses that assessing capabilities should go beyond measuring current outcomes and should also explore how these capabilities can be fostered and how individual development can be supported. Thus, it is essential not only to assess how much success students currently demonstrate but also to understand how their potential for success can be enhanced. Numerous studies have measured educational inequality and PISA data through a unidimensional lens, focusing solely on standardized test scores. However, research that evaluates educational capability from a multidimensional perspective remains limited. For instance, Addabbo et al. (2016) utilized PISA data and the MIMIC model to examine 'science capability,' arguing that assessing science education capability necessitates looking beyond mere test scores.

Similarly, Tsai et al. (2017) explored inequalities in student performance across mathematics, science, and reading through the lens of the Capability Approach, accounting for both family and school contexts. Their work underscores the critical importance of adopting a multidimensional framework when analyzing equity in education and student performance. However, no study has been found that examines mathematics capability (as a latent construct that merges cognitive achievement, anxiety, motivation, and self-efficacy) in conjunction with transformational factors (gender, socioeconomic status) on the basis of CA.

This study distinguishes the construct of '*mathematics capability*' from the narrower concepts of '*mathematical ability*' or '*competence*.' While mathematical ability conventionally refers to achieved cognitive outcomes—such as standardized test scores within a human capital framework—mathematics capability, grounded in Sen's theoretical framework, encompasses a student's broader substantive freedoms and real opportunities. This perspective transcends mere cognitive achievement by integrating vital affective dimensions, including self-efficacy, motivation, and the absence of anxiety. Collectively, these elements empower individuals to effectively mobilize and utilize mathematics in diverse life contexts (Addabbo et al. 2016; Walker and Unterhalter 2007). In order to operationalize this multidimensional latent structure, the specific variables integrated into the MIMIC model are delineated in the following section.

2 Operationalizing mathematics capability

Numerous factors, ranging from individual characteristics to systemic policies, act as determinants of student performance and, more broadly, define a student's capability set (ERI, 2009; Tabak, 2019; World Bank, 2010). Grounded in the Capability Approach, these variables can be categorized into three primary dimensions: individual characteristics, familial factors, and school-related environments (Hanushek and Woessmann 2011).

Among individual characteristics, gender emerges as a pivotal conversion factor (Pitsia et al. 2017; Rajchert et al. 2014). PISA results demonstrate that girls in OECD countries tend to outperform boys in reading, whereas boys often perform better in mathematics (OECD 2019). This gender gap reflects persistent inequalities in educational opportunity. Despite progress in female educational participation over the past decade, disparities in mathematics and numeracy remain evident. Boys continue to outperform girls in these domains, often due to gender stereotypes and cultural norms. Such influences contribute to girls' anxiety and lack of confidence in mathematics. Moreover, female students are often less inclined to choose STEM-related fields, which negatively affects their employment prospects and future income levels (Encinas-Martín and Cherian 2023; UNESCO 2020).

Familial background, particularly socioeconomic status (SES) and parental education, significantly shapes the real opportunities available to students. In Turkey, the gap between students from advantaged and disadvantaged backgrounds remains pronounced, with SES being a primary predictor of access to quality education (TEDMEM 2021). Furthermore, maternal education acts as a critical catalyst for daughters' academic success (Ferreira and Gignoux 2010), while low household income often forces a prioritization of male education, reinforcing existing inequalities (ERI, 2009). Families with highly educated parents tend to raise children who are more successful academically and develop key competencies that aid in career advancement (Sullivan 2001). Research by Coleman et al. (1966), Davis-Kean

(2005), Halle et al. (1997), Bouhlila (2017), Marks (2016), Reparaz and Sotés-Elizalde (2019), Schneider and Lee (1990), Pong (1997, 1998), and Manning (1998) support these findings (Cited in Çağlayan Akay & Oskonbaeva, 2024).

In the context of educational opportunity, immigrant status is also considered an significant component of a family's socioeconomic background. Migration can disrupt students' educational trajectories, particularly when families face adaptation challenges in a new country. Migrant children may experience educational setbacks due to limited access to resources or the need to work alongside their parents to support the household income (Bhat 2022; Şimşek 2019). Finally, school- and teacher-related variables — such as school type, classroom environment, physical resources, and teacher qualifications — also significantly influence student performance. A positive school climate, along with a strong sense of belonging among both students and teachers, has been demonstraten to enhance learning outcomes. Numerous studies underscore the critical role of these factors in shaping student achievement (Aristizábal et al. 2017; Bosworth 2014; Giambona and Porcu 2018; Meroni et al. 2015; Wilson 2011).

The UNESCO (2020) Global Education Monitoring Report, titled ALL means ALL, underscores that poverty and inequality are the biggest barriers to learning. In low- and middle-income countries, students from the wealthiest households are twice as likely to possess basic reading and math skills as those from the poorest backgrounds. The report also identifies other key variables — including gender, ethnicity, refugee status, socioeconomic background, curriculum, teacher characteristics, and classroom climate — as central to understanding disparities in student performance.

In the context of the MIMIC model, these socio-economic and demographic variables (e.g., immigrant status, school climate, and teacher qualifications) are treated as exogenous causes that constitute the latent mathematics capability. On the other hand, the measurement component of the MIMIC model comprises indicators that represent the manifest outcomes of the latent variable—namely, the 'functionings' in Sen's terminology. These indicators reflect the multidimensional nature of mathematics capability by integrating both cognitive and affective domains. While mathematics literacy serves as the primary measure of achieved cognitive performance, the model incorporates crucial affective and attitudinal dimensions such as mathematics self-efficacy, motivation, persistence, anxiety and perceived teacher support. Together, these indicators allow for a holistic estimation of a student's underlying mathematics capability beyond mere test scores.

To move beyond unidimensional evaluations of educational inequality that rely solely on test scores, this study aims to conceptualize and measure 'mathematics capability' as a multidimensional latent construct grounded in Sen's Capability Approach. Using PISA 2022 data and a MIMIC modeling strategy, this research explicitly models how mathematical functionings (i.e., cognitive achievement and affective dimensions such as self-efficacy and mathematics anxiety) serve as observable indicators of this latent capability, and how various conversion factors (e.g., gender and socio-economic status) influence the expansion or restriction of this capability among students.

3 Method

This study attempts to define the mathematics capability variable by taking a cross-section from the PISA 2022 dataset and to identify possible student, household and school-related variables that explain this defined mathematics capability variable. The PISA 2022 dataset used in this study is available as open access at https://www.oecd.org/en/data/datasets/pisa-2022-database.html. Although PISA 2022 focuses on mathematics, reading and science content, the focus is on measuring mathematical literacy and various affective characteristics related to this variable. In addition, PISA also includes Student Questionnaires to collect information from students on various aspects of their home, family and school backgrounds, and School Questionnaires to collect information from school principals on various aspects of the organization and delivery of education in schools (OECD, 2024).

3.1 Paticipants

In 2022, while countries are still dealing with the lingering effects of the COVID-19 pandemic, approximately 700,000 students from 81 OECD members and partner economies, representing 29 million people worldwide, are included in the PISA sample. This study was conducted with 196 schools and 7250 students representing 12 regions in Turkey's Nomenclature of Territorial Units for Statistics (NUTS) level 1, which took part in the PISA 2022 implementation. The average mathematical literacy score of the participating countries ranged between 336 and 575, while Turkey's average mathematical literacy score was 453. The standard error of this mean score is 1.59 and the sampling variance is 2.40. In the PISA 2022 Turkey sample, there were 3689 (50.9%) 15-year-old boys and 3561 (49.1%) girls (Ministry of National Education of Turkey 2023).

3.2 Measures

The fact that PISA 2022 went beyond mathematical literacy and test scores and measured a large number of characteristics related to this variable inspired this study. In particular, measuring variables such as mathematics teacher support, mathematics self-efficacy, mathematics anxiety in addition to test scores played an important role in defining cognitive mathematics capability. All variables that make up mathematics capability were defined in the OECD's PISA 2022 technical report (OECD, 2022) and an index value was created for each variable. The indices and details of all these variables can be found in Table 1A in the supplementary materials.

In PISA, all literacy test scores are indexed with a mean of 500 and a standard deviation of 100, while index scores for variables are indexed with a mean of 0 and a standard deviation of 1. However, this indexing is performed over the whole sample. In this study, our aim is not to make an international comparison, but to try to explain the mathematical capability of the Turkish sample. Therefore, all index values within the Turkish sample are renormalized with a mean of 0 and a standard deviation of 1.

The variation of the index values that constitute mathematics capability according to gender and the gender-based gaps are presented in Table 1. There is no statistically significant gender difference in the overall mathematics literacy score—derived by combining 10 different measures of mathematical literacy using Principal Component Analysis—or

Table 1 Descriptive statistics and t-test findings of the mathematics capability variables

Mathematics capability	Girls (n=3561)		Boys (n=3689)		Gender gap	t test
	Mean	SD	Mean	SD	F-M	
PVMATH	−0.021	0.96	0.021	1.04	−0.042	1.78
TEACHSUP	0.056	0.98	−0.054	1.02	0.110	4.68**
MATHEFF	−0.031	0.94	0.030	1.05	−0.061	2.53*
MATHEF21	−0.059	0.94	0.057	1.05	−0.116	4.89**
EXPOFA	0.028	0.95	−0.027	1.04	0.055	2.30*
EXPO21ST	0.022	0.97	−0.021	1.03	0.043	1.83
FAMCON	0.063	0.91	−0.062	1.08	0.125	5.25**
MATHPERS	0.115	0.93	−0.111	1.05	0.226	9.55**
ANXMAT	0.158	0.94	−0.154	1.03	0.312	13.26**

* $p < .05$; ** $p < .01$

in the index of "exposure to mathematical reasoning and 21st-century mathematics tasks." However, it is seen that there is a gender gap in all other indices that constitute mathematics capability. Therefore, in this study, the variables explaining mathematics capability were examined separately for boys and girls as well as for the whole sample. In the variables related to mathematics self-efficacy, "Mathematics self-efficacy: Formal and applied mathematics (MATHEFF)" and "Mathematics self-efficacy: Mathematical reasoning and 21st century mathematics (MATHEF21)", the mean scores of boys were higher than girls. Gender gaps of 0.061 and 0.116 were identified in these indices, respectively. In the indices of "Mathematics teacher support (TEACHSUP)", "Exposure to formal and applied mathematics tasks (EXPOFA)", "Subjective familiarity with mathematics concepts (FAMCON)", "Proactive mathematics study behavior (MATHPERS)" and "Mathematics anxiety (ANXMAT)", girls obtained higher index scores than boys and a gender gap occurred due to this. These average gender gaps ranged from 0.055 to 0.312.

To examine the possible effects on mathematics capabilities, 16 different exogenous variables were selected from the PISA 2022 data. These variables are individual student characteristics, household characteristics and some school-related variables. Seven of these exogenous variables are categorical and nine are index variables. Details of these variables can be found in Table 2A in the supplementary materials. Gender and immigrant status were selected as personal variables that may affect mathematics capability. 3.4% of the PISA 2022 Turkey sample is immigrant. The selected household variables are parents' education level, parents' employment status, highest parental occupational status, home possessions and ESCS. The mothers of 42.0% of the students in the PISA 2022 Turkey sample had a high school education or higher and 30.6% of them were employed. The fathers of 61.9% of the students have a high school education or higher and 86.5% of them are employed. The variables selected related to school were class periods per week in mathematics, creative school and class environment, participation in creative activities at school, ICT availability at school, disciplinary climate in mathematics, cognitive activation in mathematics: Foster reasoning and cognitive activation in mathematics: Encourage mathematical thinking variables. Students taking 2 or fewer mathematics courses per week make up 11.0% of the total sample. All nine index values, whose possible effects on mathematics capability, were renormalized with a mean of 0 and a standard deviation of 1, as in the index values that

Table 2 Descriptive statistics by gender on the exogenous variables

Indexes	Girls		Boys	
	M	SD	M	SD
Highest parental occupational status index (HISEI)	−0.037	0.98	0.036	1.02
Home possessions (HOMEPOS)	−0.018	1.00	0.018	1.00
ESCS (ESCS)	−0.058	1.00	0.056	0.99
Creative school and class environment (CREATSCH)	0.083	0.93	−0.081	1.06
Participation in creative activities at school (CREATAS)	−0.048	0.90	0.046	1.09
ICT availability at school (ICTSCH)	0.047	0.91	−0.045	1.08
Disciplinary climate in mathematics (DISCLIM)	0.114	0.95	−0.110	1.04
Cognitive activation in mathematics: Foster reasoning (COGACRCO)	0.011	0.91	−0.011	1.08
Cognitive activation in mathematics: Encourage mathematical thinking (COGACMCO)	0.022	0.97	−0.021	1.03

make up the mathematics capability variables. Descriptive statistics of all index values by gender are presented in Table 2.

Table 2 also shows the differences by gender in the external variables that are thought to affect mathematics capability. In addition, when the standard deviations are analyzed in terms of the related variables, it is seen that the variability obtained from the male student group is higher than the female students.

Also measurement invariance across gender was assessed within the MIMIC framework by inspecting the direct effects from the gender covariate to the indicators of the latent construct. The results indicated that none of the direct paths were statistically significant, and the global model fit indices showed a good fit to the data (RMSEA = 0.078, SRMR = 0.062). This suggests that the indicators function equivalently for both males and females, confirming the requirement for measurement invariance in the model. To explicitly demonstrate the equivalent functioning of the items, the direct effects from gender to each indicator were examined. The results indicated that none of these direct paths (The B coefficient ranges from 0.01 to 0.11, and the standard errors range from 0.01 to 0.03) were statistically significant ($p > .05$). The complete absence of significant direct effects from the gender covariate to any of the specific indicators confirms that there is no uniform differential item functioning. This fully supports the requirement for measurement invariance across gender in the proposed model.

3.3 Data analysis

Since this study aims to both define a mathematics capability variable and identify the possible variables that can explain this definition, the MIMIC model was used to test this purpose in the best way. Through MIMIC models, both observed outcomes can be reduced to a single latent variable (measurement model) and a large number of exogenous variables can predict the determinants of this latent variable (structural model). The MIMIC model is presented in Fig. 1. The rationale for choosing the MIMIC specification is that the latent

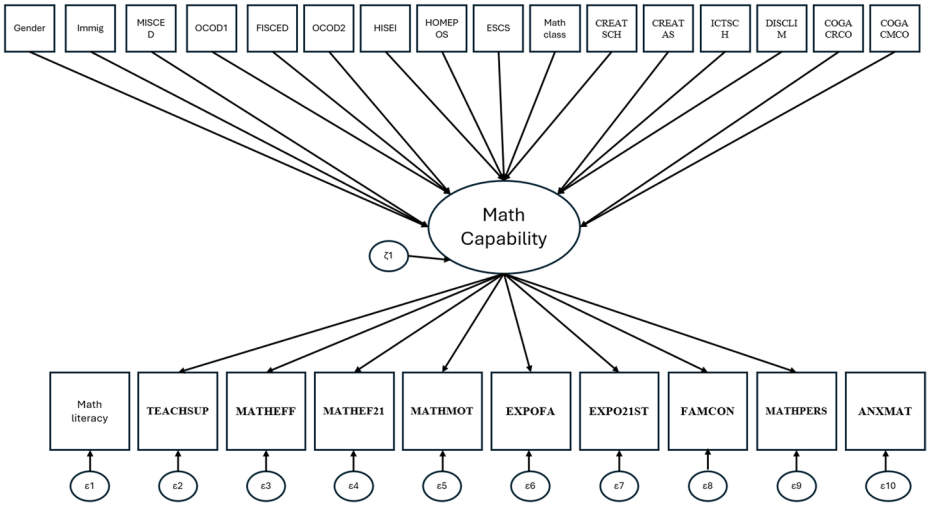


Fig. 1 Path diagram of MIMIC model

variable estimators provided by this model represent the primary objects of interest. We formulate a system of equations that determines the relationship between an unobservable latent variable Y, a set of observable internal ordered indicators Y, and a set of observable external variables X. Mathematics Capability was specified as a latent variable that occupies a structural position between its determinants and its indicators, ensuring that the construct is an estimated abstraction rather than a pre-defined index. By modeling capability as a latent factor, we explicitly partitioned the true-score variance from the measurement error, a step that is absent in standard PISA index reporting. SEM is widely used in the competency literature (Di Tommaso 2007; Krishnakumar and Ballon 2008; Kwarciński et al. 2024; Panek and Zwierzchowski 2022).

All categorical variables in the model are included as dummy variables. Index values were transformed into a distribution with a mean of 0 and a standard deviation of 1 and used in the model. In PISA 2022, 10 different plausible values were defined for mathematical literacy, one of the variables that constitute mathematics capability. It is known that choosing only one of these values may bias the findings (Buchmann and Park 2009; von Davier et al., 2009). Therefore, we used principal component analysis, which is one of the methods recommended for the use of plausible values in large-scale tests (Jewsbury et al. 2024). The use of PCA is based on the assumption that each PV is actually a different estimate of the same latent trait. By maximizing the "common variance" among these 10 values using PCA, the aim was to obtain a more stable "composite score" free from measurement error. For 10 plausible values, a single principal component was analyzed and 92.95% of the variance was explained by this principal component. This component was included in the model as mathematical literacy. All analyses were conducted separately for female students, male students and the whole sample and the findings were compared and reported. MIMIC model analyses were conducted with the lavaan package in R software (Rosseel 2012). Robust maximum likelihood was used in the parameter estimations in the MIMIC model in order to have categorical and continuous variables in the data set and to estimate parameter estimates and standard errors with low bias (Bandalos 2014). Hu and Bentler (1999) provide

the following cut-off values to show a well-fitting model: SRMR value near 0.06, RMSEA value below 0.08.

4 Findings

Non-standard regression coefficients and robust standard errors and standard regression coefficients for the MIMIC model are reported separately for the measurement model and the structural model. The robust RMSEA value for the MIMIC model was calculated as 0.080 [0.077 −0.082] for girls, 0.074 [0.072 −0.076] for boys and 0.076 [0.075 −0.078] for the whole sample. SRMR model-data fit values were 0.064, 0.061 and 0.060, respectively. These model-data fit values indicate that the MIMIC models have adequate model-data fit.

The findings obtained from the measurement model are presented in Table 3. Relative motivation to do well in mathematics compared to other core subjects was excluded from the measurement model due to the statistically insignificant regression coefficient. This variable was not part of the measurement model for both female and male students and for the whole sample. After removing this variable from the data set, the analysis was repeated. After the analysis was repeated, all regression coefficients were statistically significant at the 0.01 level and all variables except math anxiety positively predicted mathematics capability. Although there were small differences in the findings obtained according to gender, the variables that best explained mathematics capacity (with high standard regression coefficients) were Mathematics self-efficacy: Formal and applied mathematics, mathematics self-efficacy: Mathematical reasoning and 21st century mathematics, proactive mathematics study behavior and subjective familiarity with mathematics concepts. Contrary to expectations, test scores predicted mathematics capacity in fifth place. This finding shows that mathematics capacity has a meaning beyond test scores and is consistent with the related lit-

Table 3 Measurement model of the MIMIC model

Variables	Girls		Boys		All sample	
	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.
PVMATH	1.000	0.441	1.000	0.425	1.000	0.433
TEACHSUP	0.668** (0.079)	0.296	0.574** (0.082)	0.251	0.615** (0.058)	0.271
MATHEFF	1.618** (0.079)	0.742	1.751** (0.086)	0.738	1.687** (0.059)	0.740
MATHEF21	1.574** (0.092)	0.728	1.709** (0.094)	0.728	1.641** (0.066)	0.727
EXPOFA	0.701** (0.074)	0.315	0.714** (0.089)	0.306	0.710** (0.059)	0.312
EXPO21ST	0.771** (0.085)	0.341	0.711** (0.092)	0.310	0.738** (0.063)	0.325
FAMCON	1.085** (0.068)	0.512	1.410** (0.086)	0.590	1.256** (0.056)	0.555
MATHPERS	1.375** (0.094)	0.628	1.452** (0.108)	0.633	1.403** (0.073)	0.621
ANXMAT	-1.029** (0.072)	−0.468	−0.876** (0.075)	−0.383	−0.933** (0.052)	−0.411

Robust standard errors in paranthesis

** $p < .01$

Table 4 Structural model of the MIMIC model

Variables	Girls		Boys		All sample	
	Unstd.	Std.	Unstd.	Std.	Unstd.	Std.
Personal						
Gender	-	-	-	-	−0.044** (0.011)	−0.051
Immigrant	−0.018 (0.056)	−0.006	−0.044 (0.040)	−0.018	−0.034 (0.033)	−0.013
Household						
Mother degree	0.016 (0.023)	0.018	0.029 (0.021)	0.033	0.022 (0.015)	0.025
Mother oc. status	−0.007 (0.018)	−0.008	−0.026 (0.018)	−0.028	−0.017 (0.013)	−0.019
Father degree	0.038 (0.032)	0.044	−0.016 (0.031)	−0.017	0.011 (0.022)	0.012
Father oc. status	0.022 (0.026)	0.017	−0.001 (0.025)	−0.001	0.010 (0.018)	0.008
HISEI	0.051** (0.018)	0.119	0.026 (0.016)	0.062	0.038** (0.012)	0.089
HOMEPOS	0.125** (0.019)	0.289	0.086** (0.017)	0.195	0.106** (0.013)	0.241
ESCS	−0.072* (0.033)	−0.171	−0.001 (0.030)	−0.002	−0.035 (0.022)	−0.080
School						
Class periods per week in mathematics	−0.204** (0.031)	−0.132	−0.194** (0.026)	−0.151	−0.199** (0.020)	−0.143
CREATSCH	0.141** (0.011)	0.304	0.141** (0.011)	0.331	0.142** (0.008)	0.321
CREATAS	0.035** (0.009)	0.073	0.023** (0.008)	0.057	0.028** (0.006)	0.065
ICTSCH	−0.008 (0.010)	−0.017	−0.011 (0.009)	−0.023	−0.010 (0.007)	−0.020
DISCLIM	0.064** (0.010)	0.141	0.069** (0.009)	0.160	0.066** (0.007)	0.152
COGACRCO	0.027* (0.012)	0.058	0.040** (0.010)	0.094	0.035** (0.008)	0.080
COGACMCO	0.058** (0.012)	0.133	0.055** (0.011)	0.125	0.056** (0.008)	0.126

Robust standard errors in paranthesis; class periods per week in mathematics variable is coded as "=1 if 2 or fewer class periods; 0 otherwise."

* $p < .05$; ** $p < .01$

erature (Cornwell et al. 2013; Gutman and Schoon 2013). The variable that explains mathematics capacity the least is mathematics teacher support.

The findings obtained from the structural model are presented in Table 4. It was determined that gender explained mathematics capability for the whole sample. Since it was determined that the mathematics capability of boys was higher than that of girls, the mathematics capability variable was analyzed separately for male and female students. It was found that whether the students were immigrants or not had no significant effect on the mathematics capability variable. The household variables that explain mathematics capability for the whole sample are highest parental occupational status index and home pos-

sessions. Children with more household resources were found to have higher mathematics capability. It was also found that as the highest parental occupational status increased, students' mathematics capability also increased. However, whether the mother or father was employed in a profession or had a high school education or higher did not affect the mathematics capability of the students. The variables that predicted mathematics capability the most were related to school. Students in schools with more than two mathematics classes per week, in schools or classrooms where creative thinking is developed and supported, where students participate in creative activities at school, where the disciplinary climate in mathematics classrooms is high, and where mathematical reasoning is developed and mathematical thinking is encouraged have higher mathematics capabilities than other students. The development of creative thinking was the variable that explained mathematics capability the most. The high use of information and communication technologies in students' schools did not predict mathematics capability.

Focusing on gender gaps, no significant gender gaps were identified in personal and school-related variables. However, significant gender gaps were found especially in household-related variables. For girls, it was observed that an increase in the highest occupational status of the parents also increased mathematics capability. Interestingly, it was also found that a decrease in socio-economic status increased mathematics capability in girls. However, socio-economic status and parental occupational status did not affect mathematics capability in boys. The only household-related variable that predicted mathematics capability in boys was household resources.

5 Discussion

This study identified the indicators constituting the latent variable of mathematical capacity in Turkey—a country whose PISA 2022 mathematics literacy score falls below the OECD average—while also examining the predictors of this latent variable through the lens of gender differences. As a result, mathematical capacity was defined as a latent construct composed of nine indicators. The empirical existence and construct validity of this multidimensional latent structure were robustly demonstrated by the measurement component of the MIMIC model, where all selected indicators yielded highly significant factor loadings ($p < .01$) and the global fit indices (RMSEA = 0.076, SRMR = 0.060) indicated an adequate fit to the data. Furthermore, as theoretically and empirically established by Krishnakumar and Chavez-Juarez (2016), the SEM/MIMIC framework serves as a coherent and valid estimator for latent capabilities, moving beyond simple regression associations. As reported in the measurement model, while the relative motivation to do well in mathematics compared to other core subjects was excluded due to a lack of statistical significance, the remaining affective and behavioral indicators significantly contributed to the latent construct. These findings suggest that mathematics capability is shaped not only by academic achievement but also by factors such as self-efficacy, proactive study behavior, and the absence of math anxiety. This supports existing studies that emphasize the importance of evaluating student performance through both cognitive and affective lenses, rather than relying solely on test scores (Addabbo et al. 2016; Cornwell et al. 2013; Gutman and Schoon 2013; Tsai et al. 2017). The results further reinforce Sen's Capability Approach, which advocates for the use of multiple indicators to operationalize capability and argues that educational equality can-

not be assessed based on a single measure like test scores, underscoreing the importance of adopting a multidimensional framework (Krishnakumar and Chavez-Juarez, 2016; Vaughan 2007).

The most significant predictor of mathematical capacity for both boys and girls were mathematical self-efficacy. Bandura (1986, 1997) posited that self-efficacy is a revealedational factor affecting individual performance and motivation. Even when individuals possess the necessary knowledge for a given task, those with low self-efficacy may fail to act due to self-doubt. This finding aligns with numerous studies indicating a strong relationship between self-efficacy and mathematics performance (Pajares and Graham 1999; Kalaycıoğlu 2015; Schunk and Pajares 2002). Students with high levels of self-efficacy experience less anxiety when faced with challenging problems and are more likely to engage actively and exert effort in learning processes (Usher and Pajares 2008). Conversely, students with low self-efficacy often anticipate failure and may avoid engaging in learning activities. Thus, self-efficacy is considered a crucial component of students' mathematical capacity.

In the structural part of the model, it has been determined that the mathematical capacity of boys is greater than that of girls for the entire sample. Furthermore, measurement invariance across gender was rigorously assessed within the MIMIC framework by inspecting the direct effects from the gender covariate to the indicators of the latent construct. The results indicated that none of these direct paths were statistically significant, and the global model fit indices demonstrated a robust fit to the data (RMSEA = .078, SRMR = .062). This confirms that the indicators function equivalently for both male and female students (absence of differential item functioning), successfully establishing measurement invariance and ensuring that the observed gender differences reflect true disparities in the latent 'mathematics capability' rather than measurement bias. OECD reports (2019, 2021) also reveal that gender is a determining factor in mathematics performance. It is believed that the lack of equal opportunities in education is the underlying reason for this difference. Gender encompasses a significant area in discussions about equal opportunities in education. It is known that gender-based differences are shaped not only by individual factors but also by societal expectations (UNESCO 2020). While broader socio-cultural contexts and gender norms may play a role in shaping these disparities, it is important to note that our model captures associative relationships rather than testing these specific sociological mechanisms directly.

Contrary to the findings in the literature, this study determined that whether students are immigrants or not does not have a substantial impact on the mathematical capacity of male and female students. Research conducted on the academic achievements of immigrant students in Turkey demonstrates that being an immigrant has various effects on educational processes. Studies conducted in this field reveal that the academic success of immigrant students is shaped by various factors such as their language proficiency, socioeconomic status, adaptation to the school environment, and teacher attitudes (Çelik and İçduygu 2019; Erdoğan and Kaya 2015 r et al., 2021). Migrating children, in addition to being deprived of education in their own countries, may face various inequalities by experiencing adaptation problems in the countries they go to. Refugees coming to Turkey state that they have to work with their children due to financial difficulties. Therefore, they cannot send their children to school either because they work or because they do not have sufficient financial means (Bhat 2022; Şimşek 2019). In this study, the lack of impact of immigration status on mathematical capacity is attributed to the effectiveness of various efforts in recent years in Turkey aimed at integrating immigrant students into education. Projects such as Turkish lan-

guage education programs, psychosocial support services, and guidance activities initiated by the Ministry of National Education (MEB) to support the education of migrant students (Suna et al. 2021), as well as projects aimed at increasing the participation of migrant students in educational processes through collaboration with international organizations (UNICEF, 2022), can be counted among these.

It has been demonstrated through this research that the performance differences among students are also due to certain family-based and school-based factors. It has been determined that children with more home possessions have greater mathematical capacity. At the same time, it has been determined that as the highest parental occupational status index enhances, students' mathematical capacity also enhances. The findings are consistent with previous studies in the literature on factors determining educational equality of opportunity and mathematics performance (Çağlayan Akay & Oskonbaeva, 2024; TEDMEM 2021). The Coleman Report (1966) and research by Gamoran and Long (2006) have demonstraten that when educational equality of opportunity is not ensured, the academic success of students from low socioeconomic backgrounds is negatively affected, and this inequality can persist across generations. In the Turkish education system, socioeconomic factors also enhance achievement gaps by limiting access to educational opportunities for children from low-income families (Gündüz-Hoşgör and Smits 2008). In this sense, families with relatively higher incomes are more likely to implement measures that make a difference, such as purchasing quality educational tools or utilizing private tutoring and course opportunities, to ensure their children achieve better educational outcomes (Ballantine et al. 2017).

In general, OECD reports demonstrate that there is a positive relationship between students' academic achievements and their socioeconomic levels in Turkey as well; however, interestingly, this study revealed that a decrease in socioeconomic level enhanced the mathematical capacity of girls, while it had no effect on boys. Some studies have demonstraten that certain factors may influence this relationship. For example, it has been revealed that access to information and communication technologies (ICT) moderates the relationship between socioeconomic status and reading achievement (Ungan and Urfalı-Dadandı 2024; Xiao and Hu 2019; Yang et al. 2019). In other words, it has been revealed that as students' access to ICT resources enhances, the positive effect of socioeconomic status on reading achievement decreases. A similar situation may also exist between students' mathematical capacities and their socioeconomic levels. Some variables may be mediating, moderating, or regulating factors between mathematical capacity and socioeconomic level. It is important to emphasize that the MIMIC model captures an associative relationship, and this finding alone is not yet sufficient to support a broader substantive explanation. While previous studies have shown that certain factors (such as ICT access) can moderate SES effects, the specific mechanisms driving this unusual result for female students remain unclear. This situation is a less-explored area in the literature and requires more comprehensive and specific research. Additional analyses and follow-up studies—particularly those employing qualitative or mixed-methods approaches—are needed to specifically examine the underlying mechanisms of the relationship between socioeconomic status and mathematics capability among female students.

Although the economic status of families is significant for equal opportunities in education, the educational background and professional status of parents due to their job fields hold significant importance for students' performance. The lack of education among parents emerges as one of the significant barriers to girls' education (Ferreira and Gignoux 2010).

The Coleman Report (1966) revealed that the educational level of parents plays a decisive role in the academic success of children. In families where parents have a high level of education, individuals are observed to have a successful school life and to acquire significant competencies and values in terms of their career status (Sullivan 2001). In the current study, having either the mother or father working in a profession or possessing a high school or higher education did not affect the students' mathematical capacity. In addition, it has been observed that an enhance in the highest occupational status of parents (HISEI) enhances mathematical capacity in the entire group and among girls but has no effect on boys. This variable is one of the indicators used to understand how parental occupational status shapes educational equality of opportunity. HISEI, while focusing on the parent's occupational status (occupational prestige), does not include factors such as income and home resources. ESCI, on the other hand, is more comprehensive and focuses not only on the parents' occupational status but also on the entire socioeconomic environment (the educational and cultural resources available to the student at home). According to PISA results, students with a high HISEI value generally have higher average academic achievements. In countries like Turkey, students with low HISEI are generally among the disadvantaged groups in education and may have lower academic success. In this study, while the ESCI value does not affect mathematical capacity in the entire group, the impact of the HISEI value is a surprising finding. It is significant to evaluate this situation based on economic policies in Turkey. In Turkey, the relationship between occupational status and income does not always demonstrate a parallel enhance, contrary to traditional expectations. Especially in recent years, a significant portion of the educated segment of society, depending on the structure of the economy and employment, has sometimes been able to have lower income and living conditions than even the uneducated manual labor segment of the working class. Moreover, in Turkey, the relatively lower income levels of the highly educated segments compared to those with lower education levels, especially in recent years, have become a highly debated topic. These findings demonstrate the complexity of the relationship between occupational status and income in Turkey and indicate that the educated segment does not always earn higher income. Additionally, studies on gender and occupational wage inequality in Turkey demonstrate that wage differences between female and male employees are significant (Sunar 2020; TEDMEM, 2022). The research also determined that household resources are among the variables affecting mathematical capacity for both girls and boys. In fact, the only household-related variable that predicts mathematical capacity in boys is the facilities at home. The presence of resources such as the internet, computer, books, and a personal room can significantly impact students' performance. Families whose income is largely directed towards meeting basic needs and who are economically at a lower level may struggle to provide their children with a rich learning environment. Even if they are in a good economic situation, families with low cultural awareness may not see the materials that could contribute to learning as necessary in the home environment (Hart et al. 2016; Hartas 2011; Mutaf-Yıldız et al. 2020; Sikora et al. 2019).

Another finding of this research is the school variables that predict mathematical capacity. Students in schools where the number of weekly math classes is more than two, where creative thinking is developed and supported in the school or classroom environment, where they participate in creative activities at school, where there is a positive classroom atmosphere in math classes, where mathematical reasoning is developed, and where mathematical thinking is encouraged have higher math capacities than other students. Especially the

development of creative thinking has emerged as the variable that most explains mathematical capacity. This result is consistent with the literature that demonstrates that mathematical capacity is determined not only by cognitive factors but also by pedagogical approaches and learning environments. For example, Schoevers et al. (2020) state that creative thinking skills are directly related to mathematical success and that creative problem-solving abilities enhance mathematical reasoning. Similarly, Leikin (2009) and Silver (1997) demonstrate that promoting creative thinking in mathematics education enhances students' flexible problem-solving skills. Research on the impact of learning environments on mathematical capacity also supports this finding. For example, the meta-analysis conducted by Hattie (2008) revealed that one of the strongest school-based factors affecting student success is the positive classroom climate and the enhance in student participation during the teaching process. Additionally, Boaler (2016) emphasizes that mathematics education focused on creative thinking enhances students' mathematical understanding and improves their problem-solving skills. In conclusion, the findings of this research indicate that mathematical capacity is influenced not only by individual factors but also by pedagogical factors such as the learning environment, teaching processes, and the encouragement of creative thinking. Presenting mathematics education within a framework that supports constructive and creative thinking can play a critical role in enhancing students' academic success.

6 Methodological limitations

The findings of this study should be interpreted in light of certain methodological limitations. First, regarding the operationalization of mathematics performance, we utilized a Principal Component Analysis (PCA) approach to combine the plausible values. While this simplifies the analysis, it may not fully capture the imputation variance inherent in PISA's plausible value methodology. Future research should ideally employ multiple imputation techniques across all plausible values. Second, the MIMIC model inherently captures cross-sectional, associative relationships rather than strict causal mechanisms. While the existence of the multidimensional 'mathematics capability' construct is empirically supported through robust fit indices, longitudinal or mixed-methods research is warranted to empirically validate the underlying causal mechanisms over time.

6.1 Conclusion and recommendations

This research has demonstraten that students' mathematical capacity is dependent not only on academic success but also on multidimensional factors such as self-efficacy, anxiety, teacher support, study behavior, and learning environment. The findings, structured based on Amartya Sen's Capability Approach and analyzed using the MIMIC model, have revealed that test scores alone are insufficient for measuring mathematical capacity; cognitive and affective factors must be evaluated together. According to the research findings,

- The variables that most strongly predict mathematical capacity are mathematical self-efficacy, familiarity with mathematical concepts, and study behaviors.
- While male students generally exhibit a higher mathematical capacity, ESCS was found to be negatively associated with mathematics capability among female students.

- The status of being an immigrant has not demonstraten a significant effect on mathematical capacity.
- Home resources and the parent's occupational status (HISEI) are factors that particularly enhance the mathematical capacity of female students.
- Among school-based factors, environments that support creative thinking and encourage mathematical reasoning have emerged as the most influential elements on capacity.

These findings emphasize that equality policies in education should be based not only on opportunities but also on a functional understanding of equality shaped by individuals' circumstances. Based on these findings, we can make the following recommendations to policymakers, researchers, and practitioners (teachers and administrators):

- Equality in education should not be limited to access to resources. A multidimensional equality approach should be adopted. The socioeconomic status, gender, and cultural conditions of individuals should be taken into account.
- Intervention programs aimed at increasing mathematical self-efficacy should be developed. Especially, educational policies should be developed that will strengthen the mathematical self-efficacy of female students, reduce anxiety, and enhance their representation in STEM fields. For this purpose, guidance and counseling services that include gender sensitivity should be widely implemented.
- Care should be taken to ensure that the curricula are designed to develop creative problem-solving and critical thinking skills, and in-service training should be provided to teachers on these topics.
- To enhance students' belief that they can succeed in mathematics, continuous and positive feedback should be provided. Especially in the subjects they struggle with, making progress in small steps supports intrinsic motivation for success. In classrooms, teaching methods should be diversified by considering students' individual and socioeconomic differences; for example, the learning process should be personalized with practices such as cooperative learning, station work, or peer teaching.
- Tools such as digital material support, library access, free internet, and teaching materials can be provided to strengthen the home learning environment for socioeconomically disadvantaged students.
- It is believed that researching the factors explaining mathematical capacity in a comparative manner across different age groups, regions, and socioeconomic levels will make significant contributions to the literature.
- This negative association between ESCS and mathematics capability among female students warrants further inquiry and research in the literature. To better understand the underlying mechanisms of such associative relationships, mixed-method research combining quantitative and qualitative approaches is needed.
- To reveal how Turkey's specific structural inequalities are positioned in the international context, similar models should be tested in other countries, and country comparisons should be made.

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Author contributions Author-1 managed the data collection process along with the methodology and discussion sections; Author-2 performed the statistical analyses and wrote up the findings.

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Declarations

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Using artificial intelligence chatbots ChatGPT was used for proofreading of the final draft of the material.

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