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Assessment of mathematical modeling competency among undergraduates in Hebei province

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Abstract

Mathematical modeling competency, a key skill for applying mathematical knowledge to solve real-world problems, has gained increasing attention across various fields. Research indicates that students' mathematical modeling competencies are generally low. However, few studies investigate students' mathematical modeling competency, making it challenging to reflect their specific level of competency accurately. This study examines the current status of mathematical modeling competencies among undergraduates in Hebei Province. Adopting a quantitative cross-sectional survey approach, 432 undergraduates were investigated. The data were analyzed through descriptive statistics, t-test, and one-way ANOVA. The findings reveal that the total mathematical modeling competency (Mean=26.14, SD = 7.45) and the eight sub-competencies of undergraduates in Hebei Province are at a medium level. While there were no significant gender differences ($t = -0.24$, $P = 0.808$), notable differences across grade levels were observed ($F = 4.46$, $P = 0.004$). These findings have important implications for mathematics education programs. First, the lack of gender differences suggests that inclusive learning environments should continue to be promoted, ensuring equal support for all students. Second, the grade-level differences indicate the need for greater focus on developing foundational mathematical modeling competency in the early years of education.

Keywords:
Current situation, Difference test, Mathematical modeling competency, Undergraduates

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1. INTRODUCTION

In recent years, the pace of scientific and technological advancement has accelerated dramatically. Technologies such as AI and 5G networks are now widely adopted, enabling intelligent services and high-speed connectivity that reshape how individuals interact, work, and live (Attaran, 2023). This societal transformation has led to a paradigm shift in the criteria for talent selection. Employers now prioritize undergraduates who can creatively and effectively apply theoretical knowledge to solve real-world problems (Piirto, 2021). In particular, the capacity for practical problem-solving and innovation has become a core requirement for successful integration into the workforce. As higher education increasingly aims to cultivate application-oriented talent, there is growing pressure to bridge the gap between knowledge acquisition and practical implementation, especially in technical fields such as mathematics and engineering.

The field of mathematical modeling emerged in Europe and the United States during the 1960s, particularly in the domains of industrial and engineering applications (Banerjee, 2021). There is no universally agreed-upon definition of the notion of mathematical modeling competency. Various academics and researchers have put forward diverse definitions and frameworks depending on their individual research domains and viewpoints. Generally, the consensus across research is that mathematical modeling competency refers to the capacity to use mathematical knowledge to address practical problems (Geiger et al., 2021). Blomhøj and Jensen (2003) proposed that there exist two distinct interpretations of mathematical modeling competency within the academy: one from a holistic perspective and the other from an atomistic perspective.

The holistic approach conceptualizes mathematical modeling competency as a cross-disciplinary integrative ability, encompassing the entire process of problem identification, model construction, solution implementation, and reflective evaluation (Blum & Niss, 1991). This perspective emphasizes its core value in cultivating critical thinking and addressing complex real-world problems (Kaiser & Sriraman, 2006). However, the holistic definition remains overly abstract and lacks operationalizable assessment criteria, making its practical implementation in pedagogy challenging (Niss, 2015). For instance, while open-ended problem-based assessments, such as Xu et al.'s (2022) study on the pineapple peeling problem, can effectively capture holistic competency, they are constrained by subjective scoring, time-intensive procedures, and contextual limitations.

The atomistic perspective conceptualizes mathematical modeling competencies through a process-oriented framework that decomposes modeling into discrete stages (Blomhøj & Jensen, 2003; Kaiser et al., 2015). This approach fundamentally understands mathematical modeling competency through its constituent sub-competencies (Niss & Højgaard, 2019), which include but are not limited to: assumption simplification, mathematization capability, and testing proficiency. While academic consensus on specific categorizations remains elusive, scholars universally acknowledge mathematical modeling competency as a complex, multidimensional construct rather than a singular mathematical skill (Schneider et al., 2017; Zheng & Leong, 2025). The modeling process can be analytically decomposed into interconnected phases, with each stage corresponding to distinct competency components that collectively form comprehensive mathematical modeling competency. Following Haines et al. (2001) widely adopted framework, this study operationalizes mathematical mdeling competency through eight measurable sub-competencies: simplifying assumptions, clarifying goals, formulating problems, assigning variables, parameters and constants, formulating mathematical statements, selecting models, interpreting graphical representations, relating back to real situations.

Multiple-choice questions offer an effective methodology for assessing mathematical modeling competency, particularly for large-scale studies. As demonstrated by Haines et al.

(2001) and further supported by Hidayat et al. (2023), multiple-choice questions provide significant advantages in terms of scalability, scoring efficiency, and objective evaluation. This study utilizes a carefully adapted version of Haines et al. (2003) mathematical modeling competency assessment instrument, comprising 22 items that systematically examine students' ability to construct mathematical models from authentic, real-world scenarios. The instrument's design aligns precisely with our theoretical framework, covering the complete modeling cycle from problem analysis to solution verification. While multiple-choice questions formats may have some constraints in evaluating certain higher-order cognitive skills (Frejd, 2013), their practical benefits and strong ecological validity make them particularly suitable for this investigation of mathematical modeling competency development.

Mathematical modeling competency, as a crucial ability to apply mathematical knowledge in solving real-world problems, has garnered increasing attention. In today's rapidly changing world, it has become an essential skill for undergraduate students, enabling them to analyze complex practical issues and develop innovative solutions (Seçgin et al., 2024). Although educational reforms in China have placed growing emphasis on cultivating modeling skills, the actual competency levels among university students remain unclear, particularly at the regional level. Current research on students' modeling competencies indicates that while undergraduates generally possess a foundational knowledge of mathematics, they often encounter challenges such as limited modeling approaches, insufficient understanding of problem contexts, and weak mathematical transformation skills (Ferri, 2018; Kaiser, 2017). Particularly when addressing open-ended problems, significant variations emerge in students' performance in key modeling phases, including hypothesis formulation, model validation, and reflective evaluation.

However, current research on the mathematical modeling competency of university students still exhibits several limitations. The Chinese Undergraduate Mathematical Contest in Modeling (CUMCM), as a key platform, provides extensive resources for enhancing students' practical modeling skills. Table 1 shows the performance of undergraduates among Hebei province in the CUMCM. It can be seen that the undergraduates in Hebei Province have relatively low scores in the competition. Nevertheless, most related studies focus on competition winners or case analyses of specific institutions (Wang & Driscoll, 2019), resulting in a narrow overall coverage. Existing literature widely highlights significant deficiencies among general undergraduates in problem formulation, model construction, and result interpretation (Chen et al., 2020). Moreover, the majority of studies employ qualitative analysis or small-scale surveys, lacking systematic large-sample and regionally representative data, which limits the generalizability and applicability of their findings (Stanley & Robertson, 2024). Specifically, in Hebei province, systematic investigations into undergraduates' mathematical modeling competency remain scarce, particularly those incorporating detailed analyses based on variables such as institution type, academic discipline, and gender. This gap leads to insufficient understanding of the overall competency, structural characteristics, and influencing factors of mathematical modeling competency among Hebei undergraduates. Therefore, conducting a large-scale empirical study targeting Hebei Province would not only enrich the existing literature but also provide evidence-based support for regional educational policymaking and curriculum reform.

Table 1. The awards of Hebei province undergraduates in CUMCM over the past three years

Year	Category	Participation	Number of Participants	Hebei Awards Won	Percentage
2023	Undergraduate	First Prize	299	10	3.34%
		Second Prize	1200	32	2.67%
2022	Undergraduate	First Prize	299	11	3.68%
		Second Prize	1146	38	3.32%
2021	Undergraduate	First Prize	292	6	2.05%
		Second Prize	1197	41	3.43%

Existing research indicates that the development of mathematical modeling competency is influenced by multiple factors, with academic year and gender, as fundamental demographic characteristics, increasingly becoming focal points in recent studies. Blum and Leiß (2007) observed that mathematical modeling competency exhibits distinct stage-specific characteristics, with significant variations in students' mastery of abstraction, structuring, and validation across different learning phases. Therefore, investigating differences in modeling competency among students at different academic levels can reveal the progressive developmental patterns of this skill. Such comparative analyses not only provide concrete descriptions of competency disparities across grades but also offer more targeted guidance for instructional design. However, some studies primarily focus on overall competency trends within grade levels while neglecting detailed examinations of sub-processes in modeling (Hidayat et al., 2018; Zheng & Leong, 2025), resulting in an insufficient understanding of the underlying mechanisms driving competency evolution.

Regarding gender differences, Kaiser and Maaß (2007) found that gender may influence students' performance in mathematical modeling tasks. For instance, female students tend to demonstrate greater meticulousness in model validation and interpretation, whereas male students may exhibit stronger capabilities in hypothesis formulation and model construction. However, Stillman (2011) noted that such gender disparities are not universally applicable across all modeling tasks and their extent depends heavily on task design, pedagogical approaches, and cultural context. Thus, the impact of gender on mathematical modeling competency is not a simple linear relationship but rather context-dependent. This suggests that examining differences in modeling competency across academic years and gender groups can not only reveal distinct skill profiles among student populations but also provide valuable insights for educational reform and personalized teaching strategies.

Current research on mathematical modeling competency reveals three critical gaps. First, most existing studies remain limited to descriptive statistics of overall competency levels, lacking systematic evaluation and analysis of sub-competencies. Second, significant deficiencies exist in investigating grade-level differences. The majority of studies focus only on specific grade levels, failing to comprehensively reveal the complete developmental trajectory from freshman to senior years, with particularly insufficient examination of competency transitions during critical academic phases. Third, gender difference studies are not only scarce but also yield inconsistent findings. While Kaiser and Maaß (2007) reported male students' superior performance in model construction, Stillman (2011) found female students excel in model verification. More importantly, there is a lack of theoretical framework to reconcile these divergent findings, especially without adequate consideration of moderating variables such as disciplinary backgrounds and task types.

This study employs a mathematical modeling competency test to examine mathematical modleing competency across different academic years and gender groups among undergraduates in Hebei province, aiming to address these research gaps and provide empirical evidence for future pedagogical practices in mathematical modeling education. Specifically, this research seeks to address the following questions: (1) What is the current state of undergraduates' mathematical modeling competency in Hebei Province? (2) Do significant gender-based differences exist in mathematical modeling competencies among undergraduates in Hebei Province? (3) Are there notable variations in mathematical modeling competencies across different grade levels among undergraduates in Hebei Province?

2. METHOD

2.1. Research Design

Based on the research purpose and research questions, this study uses a quantitative research method to use undergraduate mathematical modeling competency test questions to investigate undergraduate mathematical modeling competency. This study belongs to cross-sectional research design.

2.2. Participants

This study was approved by the Ethics Committee of the University of Malaya and the ethical clearance letter number is UM.TNC2/UMREC_3101. Since students majoring in mathematics have learned basic knowledge related to mathematical modeling such as calculus, probability and statistics, etc., undergraduates majoring in mathematics in Hebei province were selected as the participants. Cluster random sampling was appropriate because groups rather than individuals were used for the present research. In this study, 500 questionnaires were distributed to undergraduates majoring in mathematics in Hebei province. The researchers introduced the purpose, benefits and harms of participating in this survey to undergraduates to ensure that the participants understood the study and participated voluntarily. Among them, 432 valid questionnaires were collected, with a recovery rate of 86.4%, which was suitable for data analysis. The demographic distribution of participants by gender and academic year is presented in Table 2. The gender-based classification was implemented to investigate potential gender differences in students' performance on mathematical modeling tasks. Similarly, the year-level classification was adopted to account for variations in mathematical modeling performance across different academic stages. Grouping by year level helps to explore potential developmental trends and variations in the key constructs of interest.

Table 2. Demographic distribution of participants

Statistical Characteristics	Classification	Frequency	Percentage
Grade	Freshmen	180	41.7%
	Sophomore	78	18.1%
	Junior	103	23.8%
	Senior	71	16.4%
Gender	Male	88	20.4%
	Female	344	79.6%
	Total	432	

As presented in Table 2, the study comprised 432 participants, with a gender distribution of 344 females (79.6%) and 88 males (20.4%). The sample included students across all four academic years, 180 freshmen (41.7%), 78 sophomores (18.1%), 103 juniors (23.8%), and 71 seniors (16.4%). The relatively lower proportions of sophomores and seniors may be attributed to conflicting academic commitments, with sophomores often engaged in internship programs and seniors preoccupied with graduation examinations and employment-seeking activities. Since this study compared the differences in mathematical modeling competency between genders and grades, the number of students is divided into gender and grade.

The 22-item mathematical modeling competency test was administered via the WenJuanXing online survey platform. The classification of mathematical modeling competency dimensions is shown in Table 3. Participants completed the assessment autonomously within a designated 30-minute timeframe, with flexibility to choose their optimal testing period. Due to space constraints, representative sample test items are presented below.

For clarifying the goal section, such as item 4:

"Consider the following real-world problem (do not try to solve it!):
What is the best size for bicycle wheels?
Which one of the following clarifying questions most addresses the smoothness of the ride?
A) Are the wheels connected to the pedals by a chain? B) How tall is the rider? C) Has the bicycle got gears? D) How high is the highest kerb that can be ridden up? E) Does terrain matter?

For selecting a model section, such as item 16:

Which one of the following options most closely models the height of a sunflower while it is growing (in terms of time t)?

$A. 1-e^{-t}$ $B. (1-t)^2$ $C. t$ $D. t-t^2$ $E. \frac{1}{1+e^{-t}}$

Each examination question comprises five alternatives, with one choice being entirely accurate, one to two options being slightly accurate, and the remaining options being erroneous. Choosing the fully accurate choice will result in a score of 2 points; selecting the partially correct option will result in a score of 1 point; selecting the incorrect option will result in a score of 0 points. Each question is assigned a score ranging from 0 to 2 points, resulting in a total score of 44 points. Lingefjärd (2004) posited that a score above 29 points signifies a high level of mathematical mdoeling competency, while a score below 21 points suggests a poor level. A score between 21 and 29 points aligns with a medium level. This test has garnered significant importance in the realm of mathematics education for evaluating mathematical mdoeling competency. Numerous researchers from different countries have directly utilized or modified this test to investigate the mathematical modeling skills of their students (Hidayat et al., 2018; Kaygısız & Şenel, 2023). Using the eight-dimensional scale created by Haines et al. (2003), this study provides a comprehensive and in-depth investigation regarding mathematical modeling competency among undergraduate mathematics majors.

Table 3. Mathematical modeling competency sub-dimension

Dimensions	Items
Simplifying Assumptions (SA)	1, 2, 3
Clarifying the Goal (CG)	4, 5, 6
Formulating the Problem (FP)	7, 8, 9
Assigning Variables, Parameters and Constants (AVP)	10, 11, 12
Formulating Mathematical Statements (FMS)	13, 14, 15
Selecting a Model (SM)	16, 17, 18
Graphical Representations (IGR)	19, 20
Real and Mathematical World Connections (RMC)	21, 22

2.3. Data Analysis

Assessment of data validity, reliability, and descriptive statistics is conducted using the SPSS 27.0 software. A widely used criterion in assessments of reliability is the Cronbach's alpha coefficient. The interpretation of this coefficient, which ranges from 0 to 1, follows the evaluation criteria presented in Table 4.

Table 4. Reliability analysis criteria

Cronbach's α	Criteria
>0.9	Good
0.9⩾α⩾0.7	Acceptable
<0.7	Poor

To examine the validity of the data, both the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity were conducted, with the corresponding evaluation standards shown in Table 5. At a significant level of 0.05, the skewness and kurtosis values of each item in a latent variable measurement model must be within the range of -1.96 to 1.96 to satisfy the requirements for basic normalcy.

Table 5. Reliability validity analysis criteria

KMO Value	Criteria
>0.8	Great
0.8⩾KMO⩾0.7	Good
0.7>KMO⩾0.6	Acceptable
<0.6	Poor

Data analysis was performed using SPSS 27.0 to evaluate the mathematical modeling competency of 432 undergraduates in Hebei province. The analysis aims to compute the average of the composite mathematical modleing competency and each sub-ability, as well as to compare the variations in competency between different genders and grade levels.

Utilizing SPSS27.0, a descriptive statistical analysis was performed to compute the mean and standard deviation of the overall competency and each sub-competency, therefore offering a comprehensive assessment of competency levels. Statistical analysis of frequency distributions is conducted to detect patterns within the data. Utilize SPSS 27.0 for conducting comparison analysis. A comparative analysis of competency scores between male and female students was conducted using the independent samples t test. Differences in competency scores between grades were compared using one-way analysis of variance (ANOVA). If the ANOVA findings were statistically significant, an LSD post hoc test was conducted to identify the specific differences.

3. RESULTS AND DISCUSSION

3.1. Results

The present study engaged in descriptive statistical analysis of the mathematical modeling competency and its sub-competencies among a sample of 432 undergraduates in Hebei Province. Cronbach's alpha value is 0.856 and KMO value is 0.857, the values are in line with the standards, so the mathematical modeling competency test questionnaire has good reliability and validity. Quantitative measures such as the mean, standard deviation, minimum, maximum, kurtosis value, standard error, and skewness value were computed for both the overall mathematical modeling competency and each sub-competency using SPSS 27.0, as shown in Table 6. The mean value indicates the average performance of students in each cognitive skill (Hozo et al., 2005). For example, the mean score of the problem definition component is the highest, suggesting that this skill is the student's area of greatest ability. The standard deviation quantifies the extent to which students' scores vary across different skills (Wang et al., 2014). For example, the high standard deviation of the model construction ability suggests significant variation in students' academic achievement in this skill. The minimum and maximum values present a range of scores, representing the lowest and highest levels of achievement among students in each competence, therefore illustrating the distribution of abilities. The criteria for univariate normality in a latent variable measurement model stipulate that the skewness and kurtosis values of each item must be within the range of -1.96 to 1.96, at a significance level of 0.05 (Perrier, 2009).

Table 6. Descriptive statistical analysis of MMC and sub-dimensions

Dimension	Mean	Percentage (%)	SD	Min	Max	Kurtosis	Kurtosis SE	Skewness	Skewness SE
SA	3.65	60.76	1.55	0	6	-0.53	0.23	-0.39	0.12
CG	3.56	59.41	1.59	0	6	-0.73	0.23	-0.29	0.12
FP	3.6	59.95	1.57	0	6	-0.52	0.23	-0.38	0.12
AVP	3.59	59.92	1.65	0	6	-0.8	0.23	-0.26	0.12
MS	3.69	61.42	1.77	0	6	-0.78	0.23	-0.33	0.12
SAM	3.37	56.17	1.63	0	6	-0.7	0.23	-0.13	0.12
GR	2.22	55.61	1.18	0	4	-0.74	0.23	-0.12	0.12
RMC	2.46	61.4	1.04	0	4	-0.58	0.23	-0.28	0.12
MMC	26.14	59.98	7.45	6	43	-0.18	0.23	-0.16	0.12

Based on Table 6, further detailed analysis results will be presented below. The kurtosis and skewness values of students' mathematical modeling competency and its sub-competencies fall within the range of -0.8 to 0, suggesting that the estimates adhere to a normal distribution. In terms of the general mathematical modeling competency, the average score for students is 26.14 (SD=7.45), suggesting that their overall competency is above average. The scores range from 6 to 43, indicating notable variations in undergraduates' individual levels of competency.

In terms of simplifying assumption's competency, the average score for students is 3.65 (SD=1.55), suggesting that their ability to simplify assumptions is at a moderate level. The scores range from 0 to 6, indicating discernible variations in students' levels of simplifying assumption's competency. Regarding the clarification of the goal competency, the average score for students is 3.56 (SD=1.59), suggesting that the level of accuracy in clarifying the goal competency is moderate. The scores range from 0 to 6, indicating significant variations in students' levels of clarity. The average test score for students' problem formulation competency is 3.60 (SD=1.57), suggesting a moderate level of competency. The scores range from 0 to 6, indicating significant variations in students' problem formulation competency. With regards to the competency to assign variables, parameters, and constants, the average score for students is 3.59 (SD=1.65), suggesting that their scores in this area are moderate. The scores range from 0 to 6, indicating that students Substantial disparities exist in the competency levels of assigning variables, parameters, and constants. The average score for students' mathematical statements competency is 3.69(SD=1.77), suggesting a moderate level of competency. The scores range from 0 to 6, indicating significant variations in students' mathematical statements competency levels. The average score for students' selection of a model competency is 3.37 (SD=1.63), suggesting that the accuracy level is moderate. The scores range from 0 to 6, indicating significant variations in students' selection of a model competency level. The mean value of students' graphical representations competency is 2.22 (SD=1.18), suggesting that the graphical representations competency score falls within the medium range. The scores range from 0 to 4, indicating significant variations in students' levels of competency in graphical representations. The average score for students' real and mathematical world connections competency is 2.46 (SD=1.04), suggesting a moderate level of proficiency. The scores range from 0 to 4, indicating students' real and mathematical world connections competency fall within this range. Substantial variations exist in the levels of mathematics world connections competency.

It may be concluded from the previous descriptive statistical analysis that the mathematical modeling competency and its eight sub-abilities of undergraduates in Hebei province are of moderate level. The mathematical statements competency and real and mathematical world connections competency sub-competencies are comparatively greater, though they just meet the passing standard. Hence, it is necessary to enhance the mathematical modeling competency of undergraduates in Hebei Province somewhat greater.

The followings are detailed analysis of the independent sample T-test and one-way ANOVA comparison results. The purpose of conducting an independent sample T-test is to study whether there are significant differences in mathematical modeling competency between students of different genders. The results are shown in Figures 1 to 2 and Tables 7 to 8.

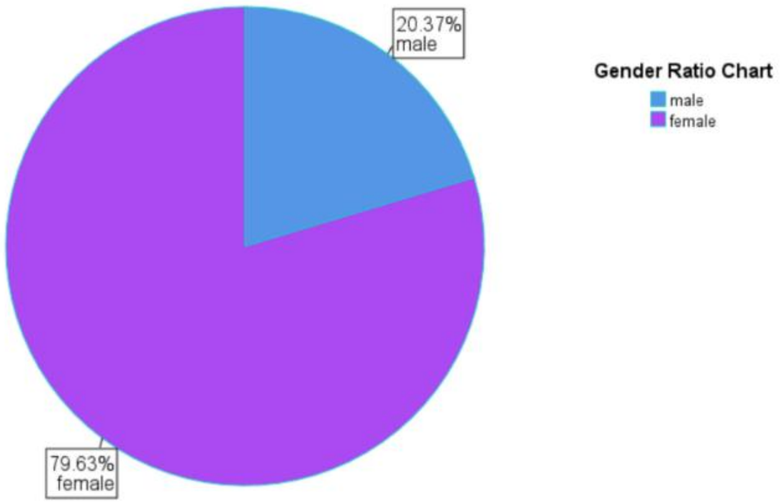

Figure 1. Gender distribution

As shown in Figure 1, the survey has the largest percentage of female participants, accounting for 79.63%, while the percentage of male participation is 20.37%, which is three times greater than the number of male participants. As previously mentioned, the sample subjects consist of undergraduate students who are majoring in mathematics. Given that many of these students will pursue careers as teachers in the future, they are particularly appealing to women. Indeed, the proportion of male and female students involved in the poll aligns with the proportion of male and female students opting for mathematics as their major in school.

Table 7. Independent samples t-test statistics

Gender	Number of Cases	Mean	Standard Deviation	t	p	Comparison of Differences
Male	88	25.966	6.768	-0.24	0.808	None
Female	344	26.183	7.624			

Based on the independent sample T-test in Table 7, the calculated t-value of -0.24 (P=0.808>0.05) indicates that there is no statistically significant difference between male and female in mathematical modeling competency. Concurrently, the t value is negative because the mean value of males' mathematical modeling competency is lower than that of females' mathematical modleing competency.

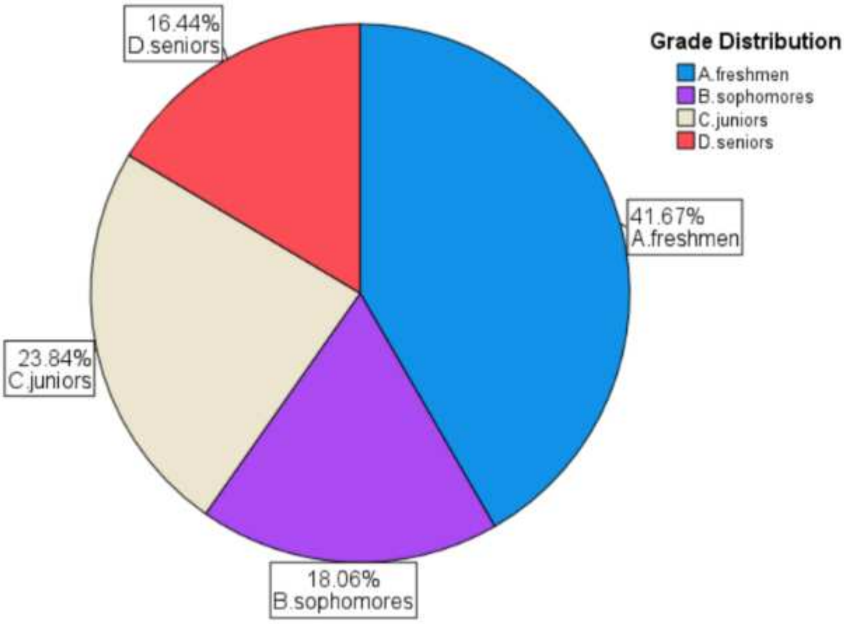

Figure 2. Grade distribution

The data presented in Figure 2 indicates that the freshmen accounted for the largest proportion of participants, at 41.67%. The sophomores had the second highest proportion at 18.06%, followed by the juniors at 23.84%. The seniors had the lowest proportion at 16.44%. Analysis indicates that the low participation rate of sophomores can be attributed to the fact that some students are engaged in internships, resulting in reduced involvement in regular school activities. Given their impending graduation, seniors are confronted with postgraduate exams and job interviews, which need them to allocate less time and energy for participation.

Table 8. Analysis of differences in MMC among different grades

Item	Freshmen		Sophomores		Juniors		Seniors	
	M	SD	M	SD	M	SD	M	SD
MMC	25.61	6.44	24.27	7.18	27.02	8.38	28.27	8.15
F	4.46							
P	0.004							
LSD	1<4； 2<3,4；							

Statistical Table 8 displays the results of the one-way ANOVA. Noteworthy from the table, F=4.46 (P=0.004<0.05). Hence, there are notable disparities in the mathematical modeling competency among undergraduates in Hebei province based on their grades. Multivariate comparisons and descriptive statistics reveal that seniors have the greatest mathematical modeling competency, with juniors following closely after. Notably, the statistical findings indicate that there is no statistically significant disparity in the mathematical modeling competency between freshmen and sophomores, as well as between juniors and seniors. Furthermore, we discovered that the mean mathematical modeling competency of freshmen surpasses that of sophomores. Even though it is only 25.61-24.27=1.34 points greater, this outcome is surprising. Thus, forthcoming study will focus on sophomores as well. The students have unique attributes that warrant further comprehensive examination.

3.2. Discussion

The Current Status of Undergraduates Mathematical Modeling Competency

The findings of this study indicate that the overall mathematical modeling competency of undergraduates in Hebei Province is at a moderate level, which addresses Research Question 1. This result aligns with prior research suggesting that students' mathematical modeling competency often remains underdeveloped without targeted intervention. For instance, Alkan and Aydin (2021) similarly reported insufficient modeling competency among students, emphasizing the need for pedagogical improvements. A more nuanced comparison can be drawn with the cross-cultural study by Yang et al. (2021), which assessed pre-service teachers in Germany, mainland China, and Hong Kong. Their findings revealed that Chinese pre-service teachers lagged behind their German counterparts, reinforcing the notion that mathematical modeling competency development in China requires systematic enhancement. Notably, the study extends this discourse by focusing on undergraduates in a specific regional context Hebei, suggesting that the challenge persists beyond teacher education. Further support comes from Kaiser (2017), who investigated mathematical modeling competency in German engineering students and found that structured modeling courses significantly improved competency. While their sample differed, their conclusion that explicit training is critical mirrors our recommendation for Hebei’s undergraduates. Despite these consistencies, our study highlights a moderate baseline competency, implying that Hebei’s students may possess foundational skills but lack advanced application. This contrasts with Kaiser (2017), where targeted interventions yielded higher proficiency. Such disparities may stem from curricular differences or cultural emphases on modeling in STEM education.

Gender Differences in Mathematical Modeling Competency Performance

This research found no statistically significant gender differences in mathematical modeling competency among undergraduates ($t=-0.24$, $p=0.808$), addressing Research Question 2. This result aligns with the findings of Borgonovi et al. (2023), who reported negligible gender gaps in general mathematical problem-solving abilities. At the same time, this study is consistent with the study of Paz-Baruch and Spektor-Levy (2024). They researched that the difference between boys and girls in the performance on the operation with numbers test did not reach a level of significance. The possible explanation for the absence of significant gender differences in this study may be the increasing emphasis on gender equity in mathematics education across Chinese universities. Students majoring in mathematics typically receive similar academic training and exposure to modeling tasks, which may minimize variability attributable to gender. However, the current findings contrast with those of Rossi et al. (2022), who found that male students tended to report higher confidence in mathematical tasks, while female students experienced greater anxiety. Such emotional factors could influence mathematical modeling competency performance. The inconsistency may be due to differences in educational contexts. Rossi et al.'s (2022) study was conducted in a Western setting, whereas the current study was situated within the Chinese higher education system, where attitudes toward mathematics and gender roles may differ substantially. Cultural expectations, teacher practices, and peer influences might all play roles in shaping students' mathematical engagement, potentially moderating the influence of gender. Since gender does not appear to be a significant factor affecting mathematical modeling competency in this context, educators and curriculum designers should instead focus on individual-level variables, such as students' metacognitive strategies or achievement goals.

Grade Differences in Mathematical Modeling Competency Performance

The current study revealed statistically significant differences in mathematical modeling competencies across different grade levels ($F = 4.46$, $p = 0.004$), thereby addressing Research Question 3 regarding developmental patterns in mathematical modeling competency. While these findings generally corroborate Ludwig and Reit's (2013) observation of progressive improvement in mathematical modeling abilities among German middle school students, our results present several noteworthy nuances that merit deeper examination. Most strikingly, we observed a modest but statistically reliable performance advantage among first-year undergraduates compared to their second-year counterparts, a pattern that diverges from the expected linear progression of skills. This phenomenon finds parallel in Blomhøj and Jensen's (2007) longitudinal work, which documented similar non-linear developmental trajectories during critical transition periods in university mathematics education. The superior performance of first-year students may be attributed to multiple interacting factors: their heightened academic engagement and motivation during the initial transition to higher education (Kahu et al., 2020; Zimmerman et al., 2017), the more applied nature of introductory mathematics courses that emphasize modeling skills, and potentially reduced cognitive load as they have not yet encountered the more abstract theoretical courses that dominate the second-year curriculum (Doerr & English, 2003). This pattern stands in contrast to Wilhelm et al.'s (2019) findings of steady linear improvement across university grades in the German context, suggesting that institutional and cultural differences in curriculum design and sequencing may significantly influence the development trajectory of modeling competencies.

This study found that undergraduates' mathematical modeling competency gradually improves with grade level, with fourth-year students demonstrating significantly higher competency than those in lower grades. This result is consistent with the findings of Cevikbas et al. (2022), who suggested that the development of mathematical modeling competency follows a staged progression. It also aligns with the conclusion of Fıtrıanı et al. (2020), which indicated that senior students exhibit stronger problem-solving skills and more effective use of modeling strategies. A possible explanation is that higher-grade students have received more systematic training in mathematics, modeling, and applied courses, thereby acquiring more theoretical knowledge and mathematical tools. These findings suggest that universities should design a progressive curriculum structure based on students' academic levels, focusing on foundational competency in the early years and strengthening comprehensive modeling practice and application in the later years. The current findings have important pedagogical implications, particularly highlighting the need for targeted instructional support during the second year to prevent the observed competency dip, perhaps through intentional integration of modeling applications in theoretical courses or specialized bridging programs. Furthermore, these results underscore the value of implementing vertically aligned modeling curricula (Lesh & Zawojewski, 2007) that maintain consistent emphasis on modeling skills across all years of study.

4. CONCLUSION

This study reveals that undergraduates in Hebei Province exhibit moderate mathematical modeling competencies, aligning with global trends and signaling a need for curriculum reforms, including structured modeling courses and project-based learning. Contrary to some prior research, no significant gender differences emerged, possibly reflecting progress in educational equity, though attention to attitudinal barriers remains crucial. Notably, grade-level analysis uncovered a non-linear competency progression, with second-year students experiencing a temporary decline—highlighting the necessity for targeted support during transitional phases. These findings advocate for a multifaceted strategy combining evidence-based pedagogy, inclusive environments, and transitional interventions. While limited by its regional scope, the study offers valuable insights for enhancing mathematical modeling competency in Chinese higher education, warranting future research in broader contexts with longitudinal designs.

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