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# An Investigation of Pre-Service Primary School Teachers' Multiple Representation Achievement in Mathematics

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## Abstract

This study investigates the multiple representation achievement in mathematics of pre-service primary school teachers with respect to gender, current undergraduate grade level, type of high school graduated from, and academic track at graduation. A causal-comparative research design was adopted. Data were collected using a researcher-developed multiple representation achievement in mathematics test comprising 13 items across five questions, each scored on a 0–4 analytical rubric, with a maximum total score of 52. After the assumption of normality was confirmed, parametric analyses were conducted, with an independent-samples t-test used for gender comparisons and one-way ANOVA followed by LSD post hoc tests employed for the remaining variables. Results indicate no statistically significant differences in multiple representation achievement in mathematics by gender, grade level, or high school type. However, a significant difference emerged with respect to academic track, with graduates of the numerical/science track significantly outperforming graduates of the equal-weight track. These findings highlight the need for differentiated instructional support within pre-service teacher education programs to develop multiple representation competencies equitably across diverse academic backgrounds.

**Keywords:** Mathematics, mathematics education, multiple representation, pre-service primary school teachers, teacher education.

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## 1. INTRODUCTION

Mathematics is not merely a school subject; since, it functions as a universal language with its own symbols and terminology that permeates numerous domains of everyday life. Yet its inherently abstract nature can make mathematics difficult to understand, fostering perceptions of the subject as inaccessible and contributing to disengagement. Primary school students, who are typically in the concrete operational stage, may experience mathematics as complex and challenging, which can in turn give rise to negative attitudes and affective dispositions toward the subject. Against this backdrop, accurately recognizing and meaningfully using mathematical language and making mathematical thinking visible in ways appropriate to children's developmental levels emerges as a core pedagogical requirement.

In alignment with the general aims and foundational principles stipulated in the Basic Law of National Education, one of the stated objectives of the Turkish Mathematics Curriculum is to enable students to 'express concepts through different representational forms' (Ministry of National Education [MEB], 2018). Other curriculum objectives further suggest that the use of multiple representations holds significant potential to support mathematical understanding and problem-solving while contributing to the development of broader mathematical competencies. Within the scope of the Türkiye Yüzyılı Maarif Model (The Century of Türkiye Education Model), mathematical representation has been formally identified as one of five core mathematical process skills, with explicit expectations for its systematic development throughout instruction (MEB, 2024). Given the growing emphasis on skill-based questioning in national and international assessments particularly PISA and the body of evidence linking multiple representation approaches to improved mathematical reasoning, problem-solving, and achievement, it becomes critically important that the representational foundations of mathematical competence are established in high quality from early childhood through the primary years. Teachers bear pivotal responsibilities in ensuring that this process is carried out effectively.

The multiple representation approach provides a framework that centers the expression of mathematical ideas in diverse forms and the construction of meaningful connections among those forms. Within this framework, multiple representations encompass a wide variety of display types used in mathematics from concrete objects and manipulative materials to everyday-life contexts, from mathematical symbols to graphs, tables, and models, and from written and oral expressions to pictures and diagrams (İzgiol, 2014). The concept of representation is understood not only as a mode of display but also as a set of tools that facilitate the cognitive processing of mathematical entities and mediate their communication to others (Delice & Sevimli, 2016). In this regard, the framework proposed by Lesh et al. (1987) comprising five interconnected representation types is among the most widely referenced models in the literature. In this model, real-world situations, verbal expressions, concrete objects, written symbols, and pictures and diagrams are positioned as the five primary representation types in mathematics; the transitions constructed among these representations during instruction are emphasized as deepening mathematical learning.

Within the multiple representation framework, real-world situation representation refers to addressing a mathematical expression or problem within an appropriate everyday context; where a direct contextual adaptation is not feasible, the teacher constructs a fictional real-life scenario (Clement, 2004). Verbal representation involves the student explaining and justifying a problem situation and its solution strategy in colloquial language through their own sentences. Concrete object representation (manipulative representation) refers to physical displays through which students experience and make sense of mathematical relationships using materials they can touch, group, and directly operate upon. Written symbol representation (symbolic representation) is the expression of mathematical thinking in written form using mathematics-specific symbols and notations such as operation signs, equality and comparison symbols, numerals, and fraction notation. Pictorial and diagrammatic representation (visual representation) encompasses the organization and presentation of mathematical knowledge through visualization tools such as figures, models, graphs, tables, and number lines, rendering conceptual meaning visible. As an illustration, in a fraction-related problem situation, the instructional sequence may begin with establishing a sharing context from daily life (real-world representation); the student's articulation of their solution reasoning (verbal representation); modeling with fraction pieces or fraction cards (concrete object representation); recording fractions and operations in symbolic form, e.g., 3/8, 2/8, 3/8 + 2/8 (symbolic representation); and finally, displaying the same relationships on an area model or number line (visual representation).

The multiple representation approach is extensively endorsed in the literature as one of the foundational instructional frameworks capable of simultaneously supporting both cognitive processes and affective outcomes. Multiple representations are defined as pedagogical arrangements that enable a mathematical concept to be re-expressed through different representation types verbal, visual, and symbolic thereby affording students multiple pathways to access the same concept (Prain & Waldrip, 2010). It has been argued that the use of multiple representations facilitates conceptual meaning-making and contributes to the development of positive attitudes toward mathematics (National Council of Teachers of Mathematics [NCTM], 2000). Sevimli (2009) specifically highlighted multiple representations as an effective instructional pathway for making sense of mathematical structures. Similarly, Van De Walle et al. (2012) contend that strengthening students' capacity to transition between representations deepens mathematical understanding and promotes retention. More recent evidence further corroborates this accumulation, indicating that multiple representation-based instruction can enhance students' reasoning levels and increase their self-efficacy perceptions related to learning (Ayyıldız Altınbaş et al., 2025).

Determining pre-service primary school teachers' levels of multiple representation achievement in mathematics will provide important indicators of their competence in constructing inter-representational transitions and deploying representations for pedagogical purposes. Furthermore, examining this achievement in relation to variables such as undergraduate grade level, high school graduation track, and school type may reveal with which educational experiences multiple representation ability is associated thereby contributing original insights to the literature. The resulting findings will also enable evidence-based inferences regarding at which stages and for which student profiles representation-focused content and practice in teacher education programs should be strengthened.

## 2. METHOD

The main purpose of this study is to investigate pre-service primary school teachers' multiple representation achievement in mathematics levels with respect to gender, type of high school graduated from, academic track at graduation, and current undergraduate grade level. In line with this purpose, the following research question was addressed:

> *Does pre-service primary school teachers' multiple representation achievement in mathematics differ significantly by gender, type of high school graduated from, academic track at graduation, and current undergraduate grade level?*

### 2.1. Research Design

In order to examine whether multiple representation achievement in mathematics differed across the specified variables, a causal-comparative research design was employed. Causal-comparative research aims to obtain generalizable findings about whether a dependent variable changes as a function of pre-existing group membership in this case, gender, school type, academic track, and grade level without any experimental manipulation of those groups (Büyüköztürk et al., 2022).

### 2.2. Participants

The sample was determined using purposive sampling, selecting individuals who met the study criterion of being enrolled in the primary school teacher education program. Participant information is presented in Table 1.

**Table 1.** *Participant Characteristics*

| Gender | N | Grade Level | N | Academic Track | N | High School Type | N |
|---|---|---|---|---|---|---|---|
| Female | 116 | 1st Year | 55 | Equal-Weight | 120 | Anatolian High School | 100 |
| Male | 47 | 2nd Year | 43 | Numerical/Science | 29 | Science High School | 8 |
| | | 3rd Year | 27 | Other | 14 | Vocational High School | 21 |
| | | 4th Year | 38 | | | Imam Hatip High School | 20 |
| | | | | | | Social Sciences H.S. | 10 |
| | | | | | | Other | 4 |
| **Total** | **163** | | **163** | | **163** | | **163** |

As shown in Table 1, 116 participants (71.2%) were female and 47 (28.8%) were male. Regarding grade level, 55 were first-year, 43 were second-year, 27 were third-year, and 38 were fourth-year students. In terms of academic track at graduation, 120 participants had graduated from the equal-weight track, 29 from the numerical/science track, and 14 from other tracks. With respect to high school type, 100 participants had graduated from Anatolian high schools, 8 from science high schools, 21 from vocational high schools, 20 from Imam Hatip high schools, 10 from social sciences high schools, and 4 from other high school types. The total sample comprised 163 pre-service primary school teachers across all four undergraduate grade levels.

### 2.3. Data Collection Instrument

A multiple representation achievement in mathematics form was developed with reference to the literature on mathematical multiple representation skills. A separate scoring rubric was also prepared for each item on the form. Both the achievement form and the scoring rubric were submitted for expert review to two elementary mathematics education specialists, one primary education mathematics specialist, and two linguistics specialists. The form and rubrics were revised in light of the expert feedback received. A sample item from the form is presented in Figure 1.

**Question 4:**

A 180-meter-long piece of fabric is being dyed at a factory, starting simultaneously from two different ends with two different colors. From one end, 4/6 of the fabric has been dyed blue; from the other end, 4/9 of the fabric has been dyed yellow. After the dyeing process, the portion of the fabric that has received both blue and yellow dye has turned green the mixture of the two colors.

a. What is the length of the green-colored portion of the fabric?

b. On the strip below, divide and color the portions formed on the whole fabric appropriately.

**Figure 1.** *Sample multiple representation achievement in mathematics item*

The scoring rubric used for evaluating responses to the multiple representation items is presented in Figure 2. Each item was scored on a scale from 0 to 4, where 0 indicated no valid attempt or a completely irrelevant response, and 4 indicated a fully correct and complete response.

| Item | Score 0 | Score 1 | Score 2 | Score 3 | Score 4 |
|---|---|---|---|---|---|
| 4a | No attempt at solution, or irrelevant solution path selected. | Appropriate solution path selected, but only the blue or yellow portion identified, or result stated without calculation. | Appropriate solution path selected; blue and yellow portions identified, but the green (mixed) portion not calculated. | Appropriate solution path; blue and yellow portions calculated; green portion computed with a procedural error, or result stated without calculation. | Appropriate solution path followed; correct result obtained. |
| 4b | No attempt, or the strip cannot be divided into an appropriate number of parts, or proportional display is not achieved. | Strip divided into the correct number of parts (or proportionally), and blue or yellow portion correctly displayed only. | Strip divided into the correct number of parts (or proportionally); blue and yellow portions indicated, but the mixed green portion not shown. | Strip divided proportionally; blue and yellow portions indicated; green portion displayed incorrectly. | Strip divided proportionally; blue, yellow, and the mixed green portions all correctly displayed. |

**Figure 2.** *Sample item scoring rubric*

## 2.4. Data Collection Procedure

After obtaining the required ethical approval from the Scientific Research and Publication Ethics Committee for Social and Humanities Sciences at Kırşehir Ahi Evran University, the achievement form was administered to volunteer pre-service primary school teachers in their regular classrooms, following permission granted by the respective course instructors. The researcher maintained a strictly non-participatory observer role throughout data collection.

## 2.5. Data Analysis

Quantitative data were obtained by scoring participants' responses to 13 sub-items across five main questions using the rubric described above. The maximum possible score for each item was 4, and the maximum total score was 52. Statistical analyses were conducted to examine whether multiple representation achievement in mathematics varied by gender, academic track, high school type, and current grade level. Before selecting appropriate tests, the normality of the score distribution and the homogeneity of variances were tested. Results are presented in Table 2.

**Table 2.** *Normality Distribution of Total Representation Scores*

| | N | Mode | Median | Mean ($\bar{x}$) | Skewness | Kurtosis | K-S | p |
|---|---|---|---|---|---|---|---|---|
| *Total Rep. Score* | 163 | 29 | 27 | 26.45 | −.134 | −.325 | .054 | .200 |

Note. K-S = Kolmogorov-Smirnov statistic.

As shown in Table 2, the mode, median, and mean of the total representation score distribution were found to be close to one another. The skewness (−.134) and kurtosis (−.325) coefficients were close to zero, and the Kolmogorov-Smirnov test yielded $p = .200$ ($p > .05$), confirming that the scores are normally distributed. The normality of the distribution is further evident in Figure 3.

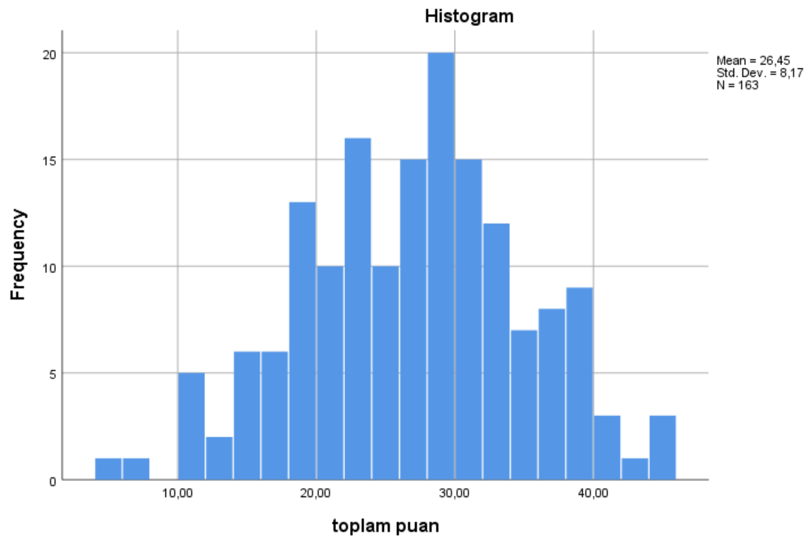

**Figure 3.** *Total score normality distribution histogram*

Since the data were normally distributed, an independent-samples t-test was used for gender comparisons, while one-way ANOVA was applied for high school type, academic track, and current grade level variables. Where ANOVA results indicated significant differences, LSD post-hoc tests were conducted to identify the source of the difference.

## 3. FINDINGS

The following sections present the findings concerning whether multiple representation achievement in mathematics differed significantly by gender, current grade level, type of high school graduated from, and academic track. Results are organized under separate sub-headings corresponding to each variable.

### 3.1. Multiple Representation Achievement in Mathematics by Gender

Following confirmation of normality, an independent-samples t-test was conducted to determine whether multiple representation achievement in mathematics differed by gender. The results are presented in Table 3.

**Table 3.** *Independent-Samples t-Test results for multiple representation achievement in mathematics by gender*

| Gender | N | Mean ($\bar{x}$) | SD | t | p |
|---|---|---|---|---|---|
| Male | 47 | 26.53 | 7.94 | −0.77 | .724 |
| Female | 116 | 26.42 | 8.30 | | |

The t-test results indicate no statistically significant difference in multiple representation achievement in mathematics between male ($\bar{x}$ = 26.53) and female ($\bar{x}$ = 26.42) participants ($t = -0.77$, $p > .05$). This finding indicates that multiple representation achievement in mathematics does not vary by gender.

### 3.2. Multiple Representation Achievement in Mathematics by Current Grade Level

A one-way ANOVA was conducted to examine whether Multiple representation achievement in mathematics differed across the four undergraduate grade levels. Descriptive statistics are presented in Table 4.

**Table 4.** *Descriptive statistics for multiple representation achievement in mathematics by grade level*

| Grade Level | N | Mean ($\bar{x}$) | SD |
|---|---|---|---|
| 1st Year | 55 | 26.51 | 8.95 |
| 2nd Year | 43 | 26.51 | 8.33 |
| 3rd Year | 27 | 28.11 | 7.52 |
| 4th Year | 38 | 25.13 | 7.28 |
| **Total** | 163 | 26.45 | 8.17 |

Examination of the mean scores by grade level reveals that the highest mean belongs to third-year students ($\bar{x}$ = 28.11), while the lowest mean belongs to fourth-year students ($\bar{x}$ =

25.13). Although mean scores appear to increase from first year through third year, they decline in the fourth year. The ANOVA results testing whether these differences are statistically significant are reported in Table 5.

**Table 5.** *One-Way ANOVA results for multiple representation achievement in mathematics by grade level*

| Source | SS | df | MS | F | p | $\eta^2$ | Post-hoc |
|---|---|---|---|---|---|---|---|
| Between Groups | 140.91 | 3 | 46.97 | .700 | .554 | 0.013 | — |
| Within Groups | 10673.50 | 159 | 67.13 | | | | |
| **Total** | 10814.41 | 162 | | | | | |

The one-way ANOVA results indicate that the difference in multiple representation achievement in mathematics across grade levels is not statistically significant ($F = .700$, $p > .05$, $\eta^2 = 0.013$). The effect size is small. This finding indicates that multiple representation achievement in mathematics does not differ significantly by current undergraduate grade level.

### 3.3. Multiple Representation Achievement in Mathematics by High School Type

A one-way ANOVA was conducted to examine whether type of high school graduated from was associated with multiple representation achievement. Descriptive statistics are presented in Table 6.

**Table 6.** *Descriptive statistics for multiple representation achievement in mathematics by high school type*

| High School Type | N | Mean ($\bar{x}$) | SD |
|---|---|---|---|
| Anatolian High School | 100 | 26.52 | 8.68 |
| Science High School | 8 | 31.25 | 4.89 |
| Imam Hatip High School | 20 | 24.85 | 8.64 |
| Social Sciences High School | 21 | 26.38 | 6.41 |
| Vocational High School | 10 | 25.80 | 6.34 |
| Other | 4 | 25.25 | 10.69 |
| **Total** | 163 | 26.45 | 8.17 |

Examination of mean scores by high school type shows the following ranking from highest to lowest: Science High School ($\bar{x} = 31.25$), Anatolian High School ($\bar{x} = 26.52$), Social Sciences High School ($\bar{x} = 26.38$), Vocational High School ($\bar{x} = 25.80$), Other ($\bar{x} = 25.25$), and Imam Hatip High School ($\bar{x} = 24.85$). The ANOVA results for these differences are reported in Table 7.

**Table 7.** *One-Way ANOVA results for multiple representation achievement in mathematics by high school type*

| Source | SS | df | MS | F | p | $\eta^2$ | Post-hoc |
|---|---|---|---|---|---|---|---|
| Between Groups | 246.09 | 5 | 49.22 | .731 | .601 | 0.022 | — |
| Within Groups | 10568.31 | 157 | 67.31 | | | | |

| | | |
|---|---|---|
| **Total** | 10814.41 | 162 |

The ANOVA results indicate that the difference in multiple representation achievement in mathematics across high school types is not statistically significant ($F = .731$, $p > .05$, $\eta^2 = 0.022$). The effect size is small. Accordingly, high school type graduated from does not significantly predict multiple representation achievement.

### 3.4. Multiple Representation Achievement in Mathematics by Academic Track

To examine whether multiple representation achievement in mathematics varied by academic track, a one-way ANOVA was conducted. Descriptive statistics are given in Table 8.

**Table 8.** *Descriptive statistics for multiple representation achievement in mathematics by academic track*

| Academic Track | N | Mean ($\bar{x}$) | SD |
|---|---|---|---|
| Equal-Weight | 120 | 25.47 | 7.68 |
| Numerical/Science | 29 | 30.69 | 9.29 |
| Other | 14 | 26.14 | 7.52 |
| **Total** | 163 | 26.45 | 8.17 |

As shown in Table 8, mean multiple representation achievement in mathematics increased progressively from the equal-weight track ($\bar{x} = 25.47$) through other tracks ($\bar{x} = 26.14$) to the numerical/science track ($\bar{x} = 30.69$). The ANOVA results for these differences are reported in Table 9.

**Table 9.** *One-Way ANOVA results for multiple representation achievement in mathematics by academic track*

| Source | SS | df | MS | F | p | $\eta^2$ | Post-hoc |
|---|---|---|---|---|---|---|---|
| Between Groups | 638.62 | 2 | 319.31 | 5.021 | .008 | 0.059 | NS > EW* |
| Within Groups | 10175.79 | 160 | 63.60 | | | | |
| **Total** | 10814.41 | 162 | | | | | |

Note. NS = Numerical/Science track; EW = Equal-Weight track. Post-hoc comparisons based on LSD test.

The ANOVA results indicate a statistically significant difference in multiple representation achievement in mathematics by academic track ($F = 5.021$, $p < .05$, $\eta^2 = 0.059$). The effect size is moderate. Post-hoc LSD comparisons revealed that the significant difference was between graduates of the numerical/science track and graduates of the equal-weight track, in favor of the numerical/science track. This finding suggests that pre-service teachers who graduated from the numerical/science track demonstrate significantly higher multiple representation achievement.

## 4. DISCUSSION AND CONCLUSION

The present study examined pre-service primary school teachers' multiple representation achievement in mathematics across four variables: gender, current undergraduate grade level, type of high school graduated from, and academic track. The discussion is organized around each variable, followed by broader theoretical and practical implications.

### 4.1. Gender and Multiple Representation Achievement in Mathematics

The findings revealed no statistically significant difference in multiple representation achievement in mathematics between male and female pre-service teachers ($t = -0.77$, $p > .05$). This result is consistent with a substantial body of literature indicating that mathematical achievement does not differ significantly by gender (Memiş & Arıcan, 2013; Aksu, 2012; Yücel & Koç, 2011; Dede & Dursun, 2004; İssoufou Garba, 2017). Analyzing PISA 2015 Turkey results, Batyra (2017) similarly found no statistically significant gender differences in mathematical achievement. The Eurydice report on mathematics education in Europe likewise noted that gender-related achievement differences in mathematics are considerably less marked than those in reading literacy (EACEA P9 Eurydice, 2010). In the international literature, the Programme for International Student Assessment (PISA) consistently shows that gender gaps in mathematics performance have been narrowing globally (OECD, 2019). The absence of a gender effect in this study may reflect a positive shift away from gender-based stereotypes regarding mathematical competence and affirms that multiple representation skills are accessible to pre-service teachers regardless of gender (Else-Quest et al., 2010).

### 4.2. Grade Level and Multiple Representation Achievement in Mathematics

Although mean achievement scores showed a modest increase from year 1 to year 3, no statistically significant difference was detected across the four grade levels ($F = .700$, $p > .05$, $\eta^2 = 0.013$). The slight upward trend observed through year 3 may be attributable to the Mathematics Teaching I and II courses offered in the third year of the Primary School Teacher Education undergraduate curriculum (YÖK, 2018), which explicitly address mathematical representations and pedagogical content knowledge in mathematics. However, the decline observed in year 4 when pre-service teachers focus on practicum placements may suggest that specific instructional emphasis on multiple representations is not sustained in the final year. Comparable studies examining the relationship between undergraduate program year and multiple representation achievement in mathematics are limited, which may itself reflect the relative novelty of investigating representation achievement as a distinct construct across program years. The absence of significant grade-level differences could also be a methodological artifact: since the same test items were used across all grade levels, a test calibrated to learning progressions within the program might yield different patterns (Cai, 2005).

### 4.3. High School Type and Multiple Representation Achievement in Mathematics

The analysis revealed no statistically significant difference in multiple representation achievement in mathematics by high school type ($F = .731$, $p > .05$, $\eta^2 = 0.022$). This finding contrasts with studies in the Turkish higher education literature reporting that type of secondary school attended significantly influenced mathematics achievement (Güzeller, et al., 2016; Aksu, 2012; Narlı & Başer, 2008). Several explanations may account for the null result. First, increasing standardization in secondary education quality across school types in Turkey may have reduced pre-existing achievement gaps among graduates of different schools. Second, the extensive supplementary tutoring widely pursued by Turkish university applicants may have homogenized achievement levels irrespective of school type (Tansel & Bircan, 2006). Third, since all participants qualified for and enrolled in the same undergraduate program via the competitive university entrance examination, a selection effect may have narrowed the range of mathematics achievement at program entry making school type a relatively weaker predictor within an already filtered sample.

### 4.4. Academic Track and Multiple Representation Achievement in Mathematics

A statistically significant difference in multiple representation achievement in mathematics was found by academic track ($F = 5.021$, $p < .05$, $\eta^2 = 0.059$). Post-hoc LSD comparisons identified the source of this difference as being between graduates of the numerical/science track and graduates of the equal-weight track, in favor of the former ($\bar{x} = 30.69$ vs. $\bar{x} = 25.47$). This finding is consistent with Çiçek (2017), who reported a significant positive relationship between academic track and mathematics achievement among Turkish university students, attributing the advantage of numerical track graduates to their greater volume of mathematics coursework at the secondary level. A richer and more intensive mathematics curriculum with heightened emphasis on formal symbolic reasoning and structured problem-solving may equip numerical track graduates with deeper conceptual knowledge and more flexible representational thinking (Ball, et al, 2008; Krauss et al., 2008). The theoretical framework proposed by Lesh et al. (1987) underscores that proficiency in multiple representation requires both content knowledge and the capacity to construct fluid transitions among representational forms; it is plausible that extensive secondary-level mathematics experience contributes to the development of this capacity. These findings are consistent with the broader mathematics education literature, which emphasizes the foundational role of prior mathematical knowledge in developing pedagogical content knowledge, including representational fluency (Shulman, 1986; Ma, 1999).

### 4.5. Implications and Recommendations

The findings of this study indicate that among the variables examined, only the academic track significantly predicted pre-service primary school teachers' multiple representation achievement. Gender, current grade level, and high school type did not produce statistically significant differences. These results carry important implications for teacher education.

The significant advantage of numerical track graduates suggests that prior exposure to formal, intensive mathematics instruction constitutes an important foundation for developing multiple representation competencies (Hill et al., 2005). Teacher education programs may benefit from incorporating differentiated instructional approaches particularly targeted activities designed to strengthen concrete, visual, verbal, and symbolic representation skills for pre-service teachers from non-numerical academic backgrounds. The Elementary Mathematics course within the Primary School Teacher Education program (YÖK, 2018) offers a strategic opportunity to address this representational knowledge gap, helping to establish more equitable development of multiple representation competencies across diverse academic cohorts.

The finding that grade level within the program did not significantly influence achievement also points to the need for systematic, curriculum-embedded development of representational knowledge across all four years of teacher preparation, rather than its concentration in a single course. Multiple representation-focused content and practice should be scaffolded progressively throughout the program to support the sustained growth of this competence (Ponte & Chapman, 2008). Future research may investigate the relationship between pre-service teachers' multiple representation achievement in mathematics and their pedagogical content knowledge for teaching mathematics, as well as the impact of representation-focused instructional interventions on both achievement and classroom teaching practices. Longitudinal designs and performance-based assessments may provide additional insights into the developmental trajectory of representational competence in teacher education.

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